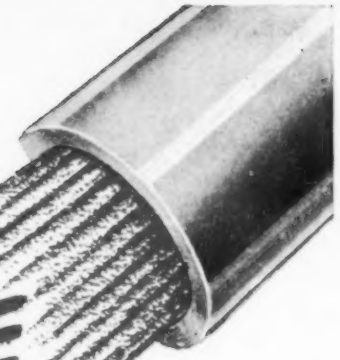
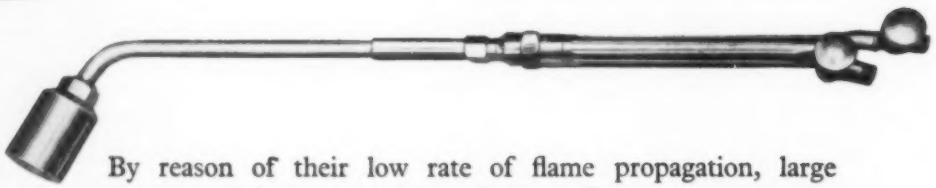
the new B.I.G.



INTENSE HEAT

Propane Heating Torch

HARRIS DESIGN



By reason of their low rate of flame propagation, large volumes of fuel gases such as Propane, Pyrogas, etc., can be safely mixed with Oxygen without the danger of the flame back-firing. The larger the volume of gases mixed, the greater the flame and the resulting heat value. The new B.I.G. PROPANE Heating Torch uses this principle with truly remarkable results.

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Inside front cover

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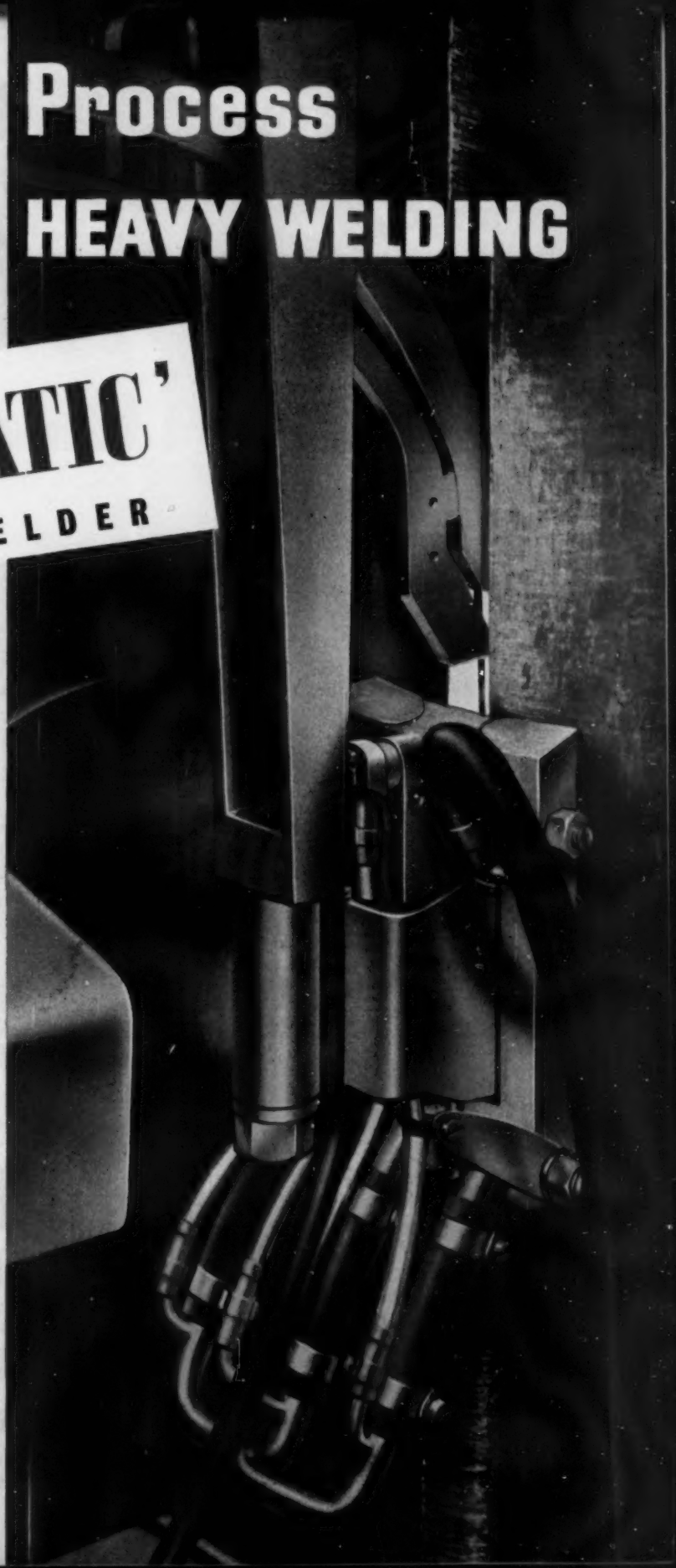
'VERTOMATIC'

VERTICAL WELDER



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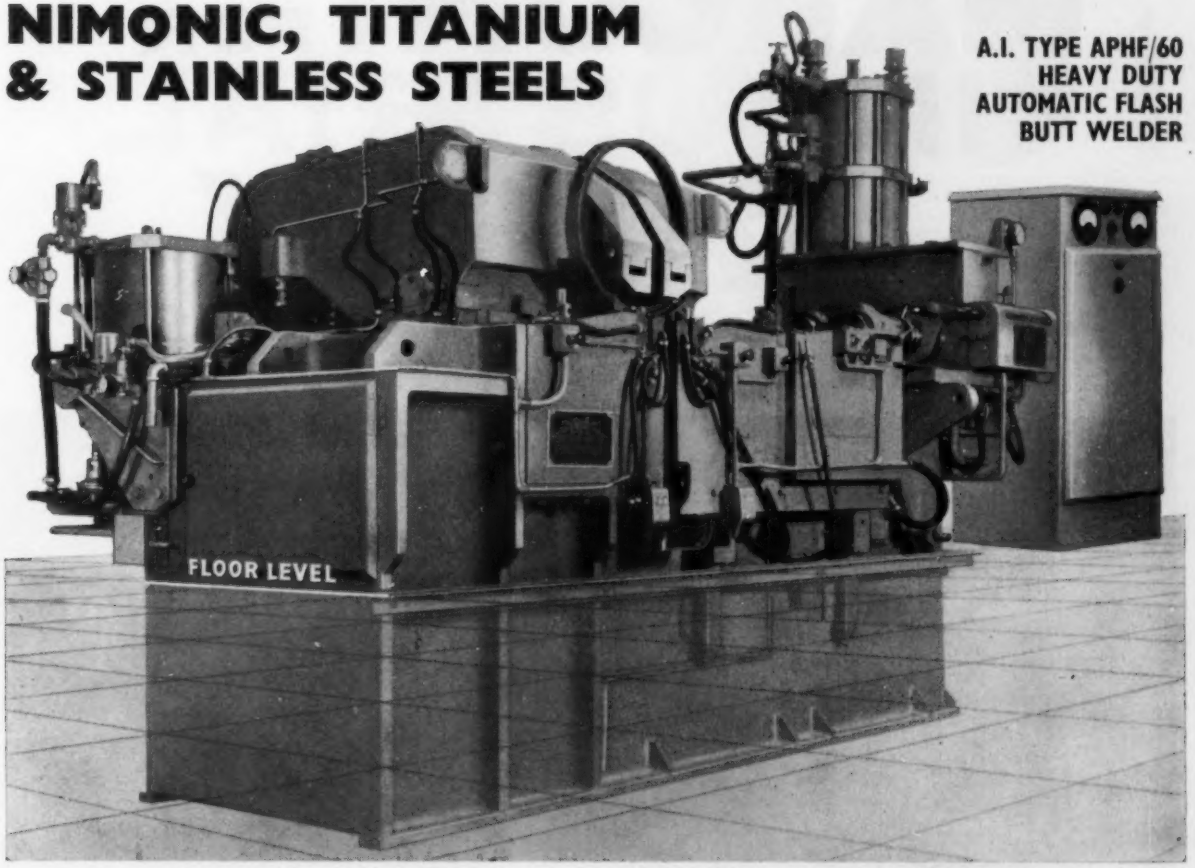

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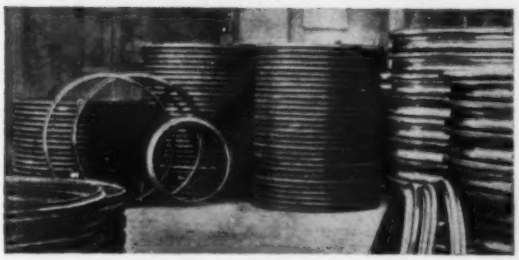

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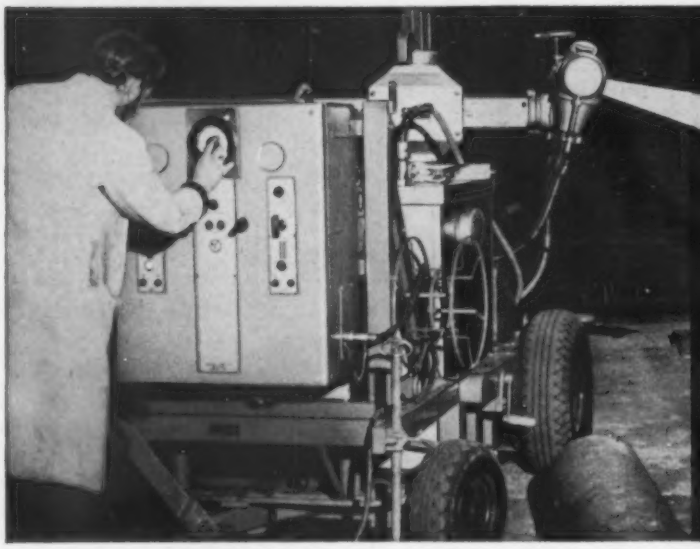

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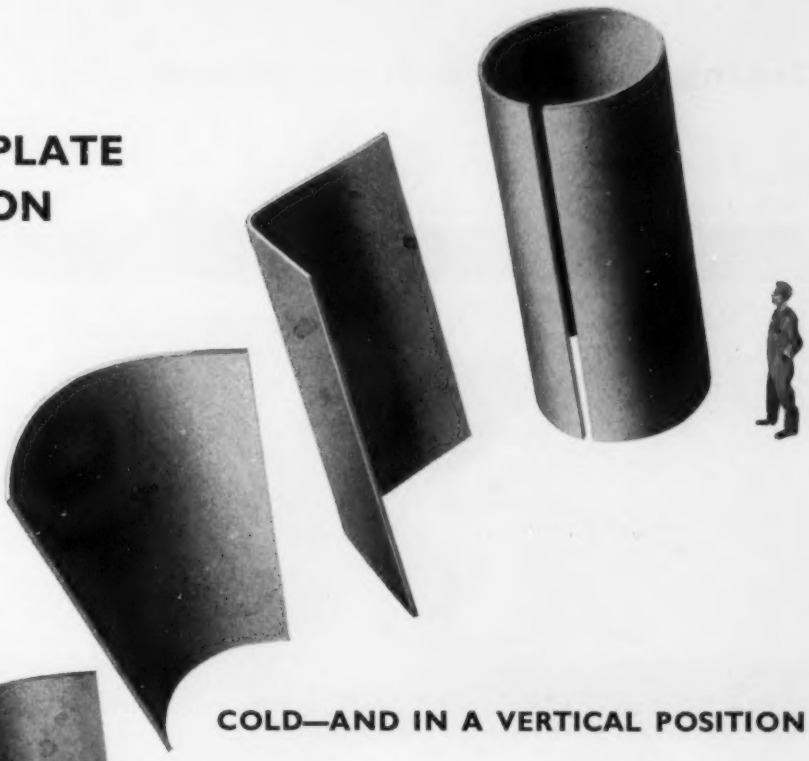
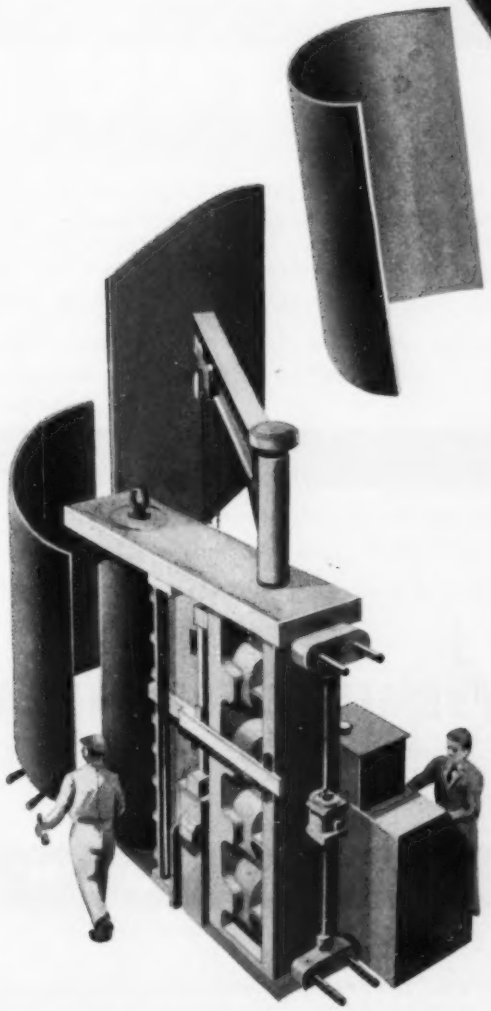
IX24

HEAVY STEEL PLATE MANIPULATION



COLD—AND IN A VERTICAL POSITION



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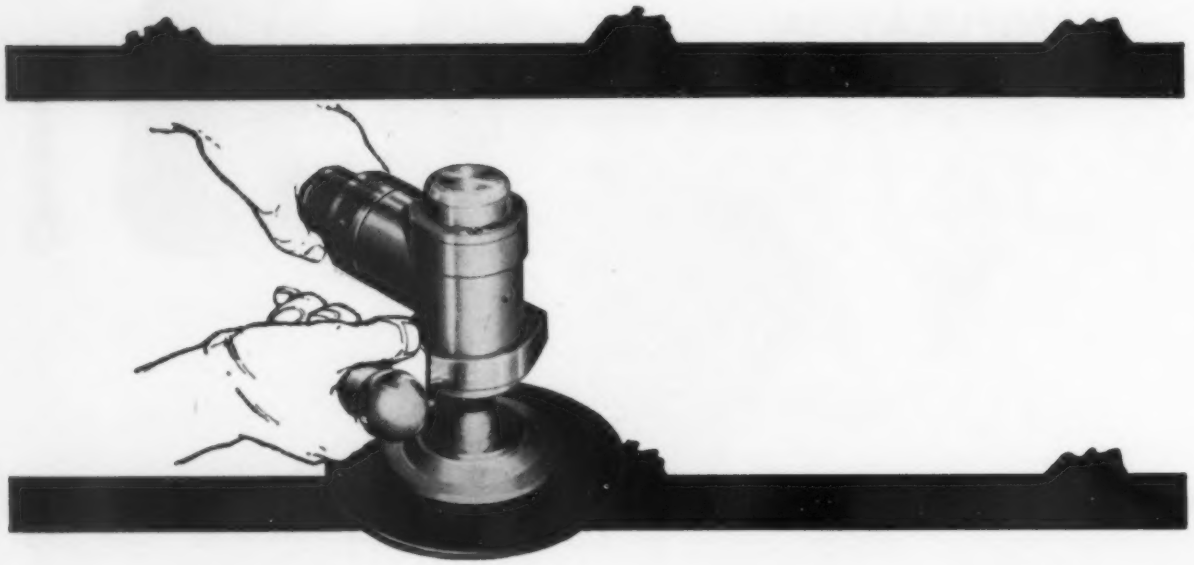

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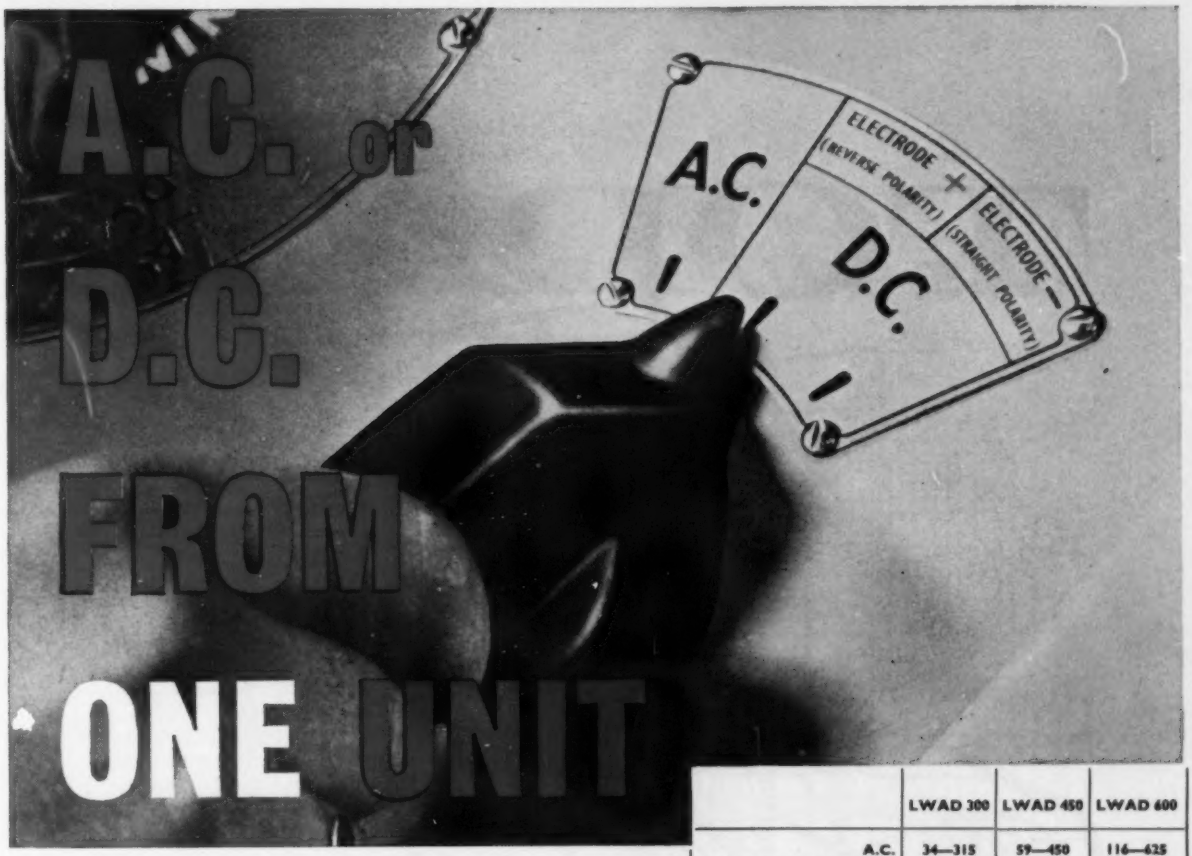

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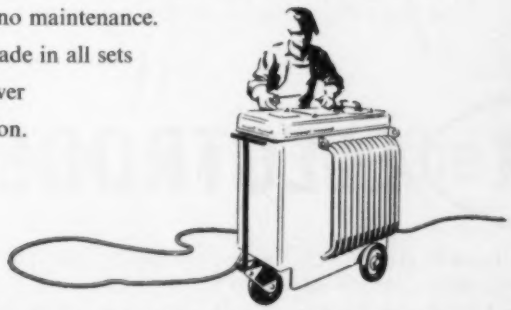

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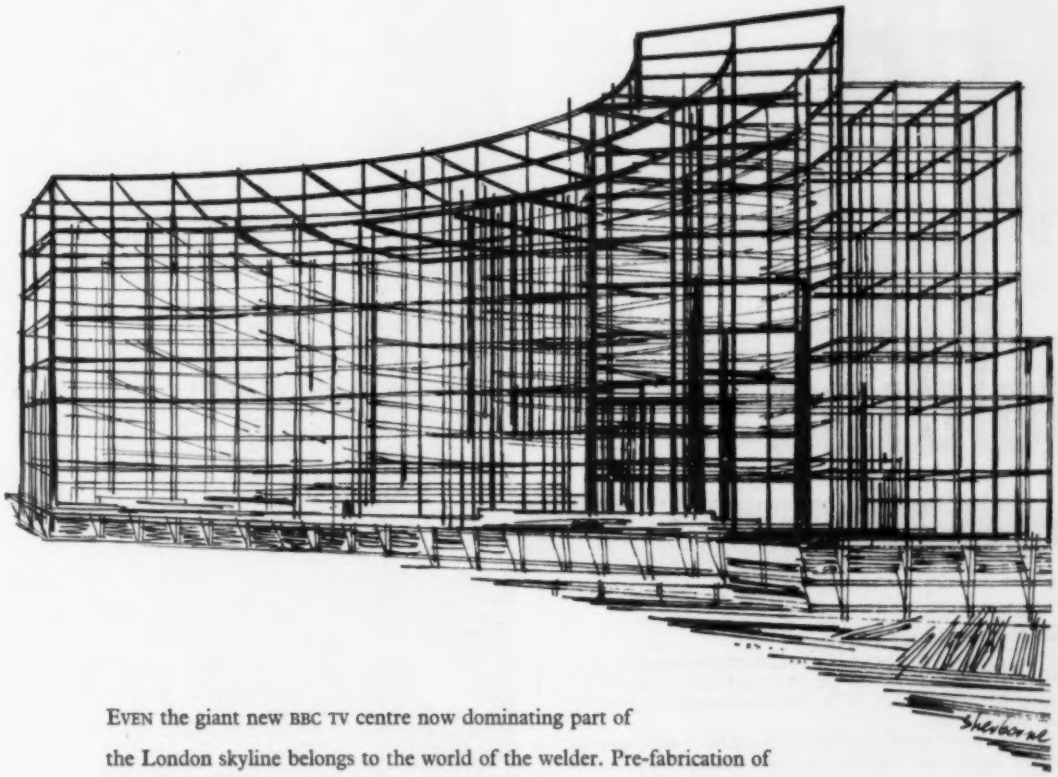

EVEN the giant new BBC TV centre now dominating part of the London skyline belongs to the world of the welder. Pre-fabrication of the steel framework, by Messrs. T. C. Jones & Co. Ltd., Treorchy, for this remarkable building was made possible by welding – with AEI electrodes.

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Types	Maximum Demand* (kVA)	Maximum average* anode current (Amps.)	Temperature control
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BK 24	1200	140	—
BK 24A	1200	140	Integral
BK 24B	1200	140	Clamp on
BK 34	2400	355	—
BK 34A	2400	355	Integral
BK 34B	2400	355	Clamp on
BK 42	600	56	—
BK 42A	600	56	Integral
BK 42B	600	56	Clamp on
BK 66	300	22·4	—

* Ratings are for welder control service, with two valves in inverse parallel at any voltage from 250-600v. r.m.s.

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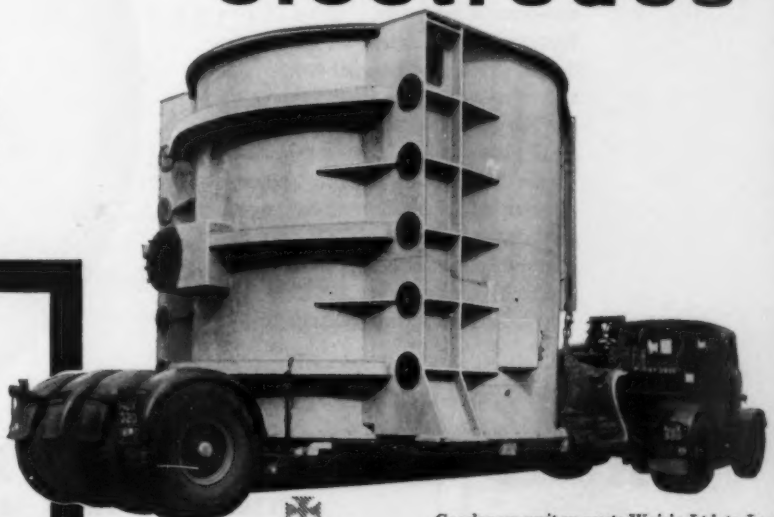

Condenser unit en route Weir's Ltd. to Leeds.

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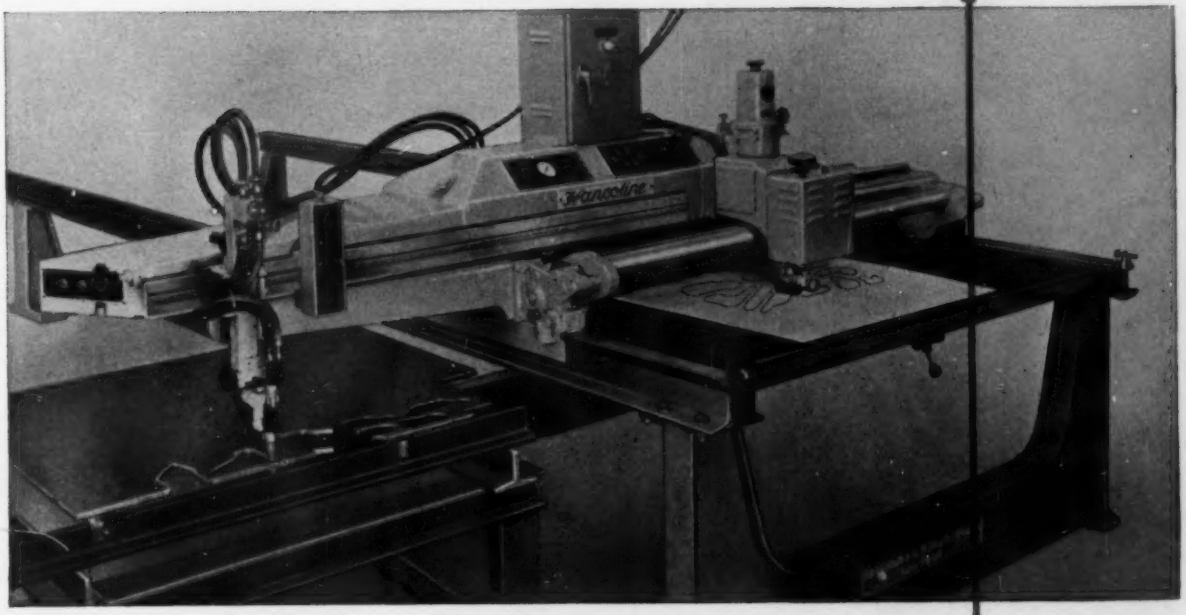

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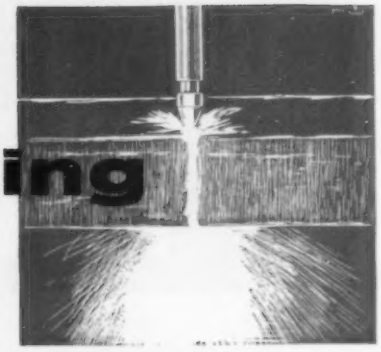
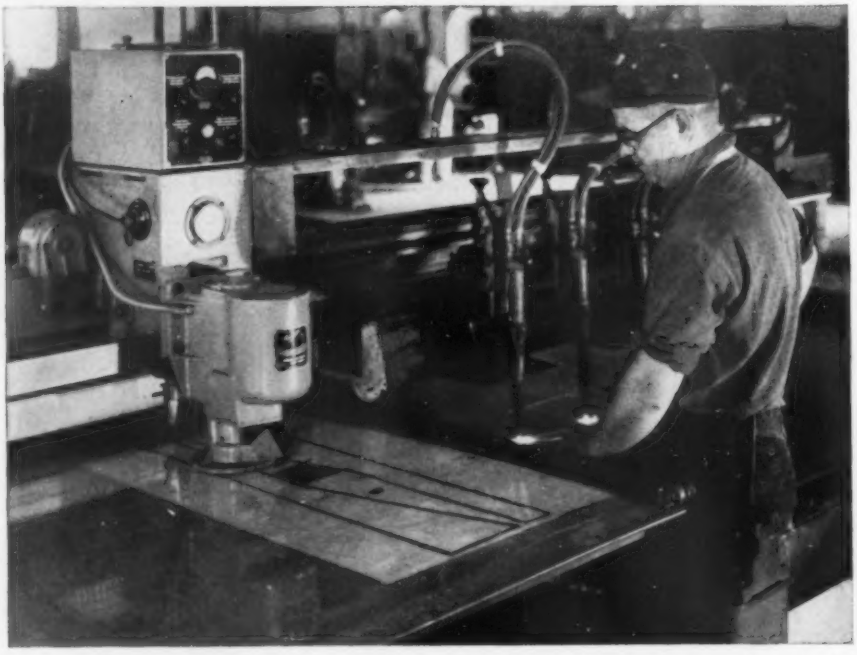


'STATOSEC 2000' universal flame cutting machine working range 118″ x 80″ x 12″



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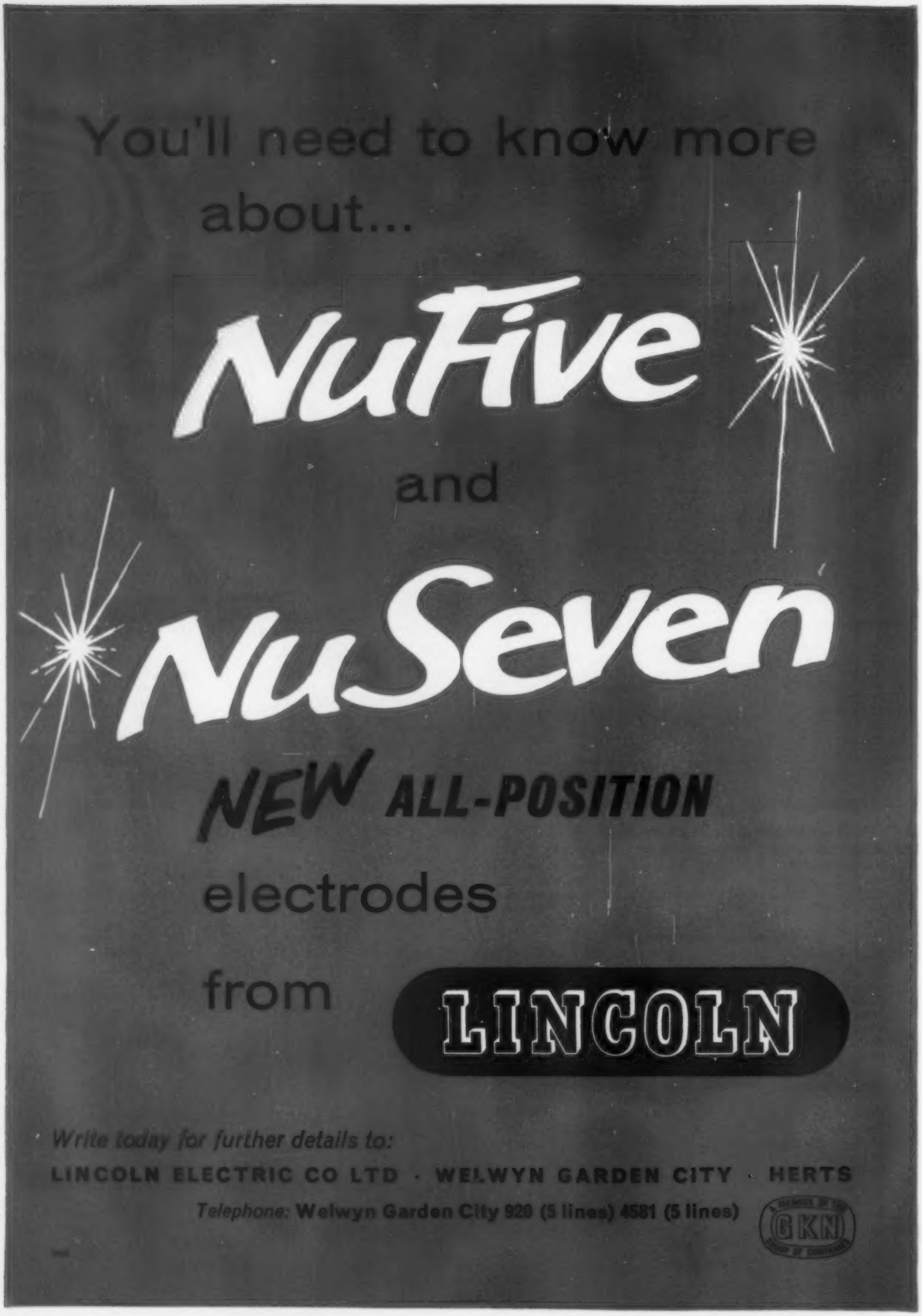
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BRITISH WELDING JOURNAL

OFFICIAL JOURNAL OF THE INSTITUTE OF WELDING AND THE BRITISH WELDING RESEARCH ASSOCIATION

Incorporating the *TRANSACTIONS* of the Institute and *WELDING RESEARCH*

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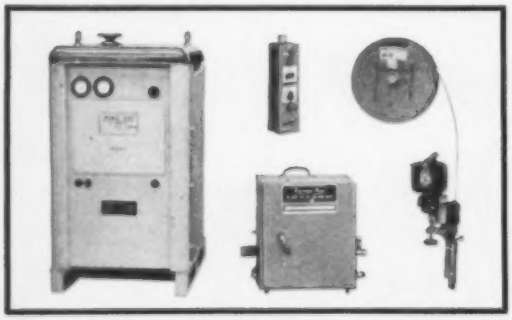

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REPORT OF COUNCIL FOR 1959

The Thirty-seventh Annual Report of the Council on the activities of the Institute during the twelve months ended 31st March 1960, was submitted for the approval of members at the Annual General Meeting on Thursday, 14th July, 1960. 586

ANNUAL REPORT

Honorary Officers and Council

The Honorary Officers and Council elected in 1959 took office after the Annual General Meeting on 16th July 1959. Mr. E. Seymour-Semper delivered his Presidential Address to members at the opening of the Autumn Meeting in London on 3rd November 1959, and took as his subject "*Education in Welding*". The address was printed in the *Journal* for December 1959.

The immediate Past President, Mr. John Strong, presented a gilt sun-ray clock to the Institute, which was installed in the Council Room, and accepted with the thanks of the Council by the President in March.

Education for Welding

The Presidential Address marked the opening of a vigorous campaign to bring home to education authorities and the engineering industries the serious gap in the national system of technical education in respect of advanced instruction in welding. Mr. Seymour-Semper made this the subject of numerous speeches to Branches throughout the country, and in January set up a special Presidential Committee on Educational Policy, which is preparing a report for the Council. As a result of these efforts, contact has been made with the Ministry of Education, the Minister of Science, and the engineering departments of several universities and technical colleges. It is intended early in 1960 to organize a special conference of educationists and industrialists to examine the needs of industry and the possibilities of meeting them by the provision of at least one post graduate course in welding engineering.

Meetings

The Spring Meeting was for the first time held in London from 20th to 24th April 1959, advantage being taken of the Engineering, Marine, Welding and Nuclear Power Exhibition at Olympia. Four papers on the low temperature properties of aluminium, and four papers on aspects of the economics of welding were presented and discussed in morning sessions, and a number of works visits were arranged, the meeting concluding with the Joint London Branches Dinner on the Friday evening.

The Autumn Meeting, also held in London, from 3rd to 6th November 1959, was a joint one with the Société des Ingénieurs Soudeurs of France, nearly fifty of whose members attended. The programme included a choice of works visits for the French visitors, and three discussion meetings, at which fifteen papers, eight by English and seven by French authors, were presented and discussed in both languages, with the aid of an interpreter. The papers had been preprinted in the journals of the two societies, each being responsible for publishing the full text of papers by its own members, and summaries of those by members of the other society.

The French visitors joined in the opening Reception and also in the Annual Dinner, the attendance at which exceeded four hundred for the first time since the war. The Guest of Honour was Sir Edward Boyle, Financial Secretary to the Treasury, and other speakers were Monsieur de Jessy, President of the Société des Ingénieurs Soudeurs, Mr. John Strong, Past President of the Institute, the Rt. Hon. Lord Harvey of Tasburgh, and Professor O. A. Saunders.

The Third Annual Lecture was given by Mr. W. G. John, a Deputy Director of Naval Construction at the Admiralty, on 3rd March 1960, on the subject of *Welding and the Design of Ships*.

An innovation of the year was a Christmas Lecture to Young People, which was delivered by Professor Hugh O'Neill at the Institute on 4th January, the title being *The Magic Arc*. Another was a Conversazione on 4th February 1960, to illustrate the work of the Technical Commissions of the International Institute of Welding, and the part played by the British Delegation in it. Speakers included the President, Mr. E. Seymour-Semper, Mr. A. Robert Jenkins, Dr. Richard Weck, Dr. A. A. Wells, and Mr. S. M. Reisser.

On the afternoon of 1st October 1959, a special meeting on Electro-Slag Welding was held, at which two papers by British authors were presented and discussed, and Professor N. N. Rykalin contributed an important account of the development of this Russian process.

Publications

Progress was made with the planned expansion and improvement of the *British Welding Journal*, which it is intended to effect piece-meal as opportunity offers. The February issue of 1960, containing papers delivered at the Birmingham University Conference on *The Electric Arc in Welding*, contained the first colour illustration printed in the *Journal*. This group of papers has been reprinted as a separate. Another feature of the year has been the increasing number of reports and other documents coming forward from the International Institute of Welding. It is the policy of the *Journal* to publish as many of these as space will allow.

From July 1959 the Institute has been in full control of the *Journal*, having taken over the management of the advertisements section from that date. The first results are encouraging.

A list of the Honorary Officers and Council for 1959–60 appears on p. 21 of this issue (Advert Section).

No books were published during the year, but work was going forward on the *Handbook for Welding Design*, a revised List of Welding Specifications and Codes, a booklet on Site Welding, a handbook on Inert Gas Arc Welding, and a revised edition of the Health and Safety booklet. Negotiations were also in progress for the publication by the Institute of two IIW publications—*Recommended Welded Connections for Pressure Vessels* and the *Handbook on Radiographic Apparatus and Techniques*.

Education Committee

While its Chairman and Vice-Chairman serve on the President's Committee on Educational Policy, the Education Committee has continued to be responsible for the execution of the Institute's present educational policy. In particular, it has reviewed and made adjustments to the administration of the Associate-Membership examination and has continued to advise technical colleges on the syllabuses of special welding courses and to assist them to obtain the services of suitable lecturers in this connection. An encouraging development during the year has been the organization at one technical college of a special course, for post H.N.C. students, in preparation for Section C (Arc Welding) of the Associate-Membership examination.

Arising out of the welding course for teachers of engineering up to H.N.C. level which was oganized by the Manchester College of Technology in association with the Institute in the summer of 1959, the Committee is trying to arrange for a similar course to be held at one of the London technical colleges in 1961.

School of Welding Technology

The School has completed two and a half years of service to the British engineering industry and has organized 45 special day and evening courses which have been attended by more than 2,000 senior personnel from firms, Nationalized industries and Government departments. During this period, the knowledge of more than 300 lecturers has been made available to course-members and the School represents a most successful, co-operative venture in education. Two full-time courses are offered each month, and more than 30 separate courses covering the principal branches of industry are available. The year has been an outstandingly successful one and the following is a list of the courses held, with attendance and number of lecturers.

Day Courses			*Attendance*	*No. of Lecturers*
1959	April	Welded Structures	39	19
	May	Metal Spraying	35	6
	May	Ultrasonic Inspection	42	11
	June	Brazing Technology and Design	44	15
	June	Welded Design and Construction in General and Mechanical Engineering	43	18
	Sept.	Advanced Course for Welding Engineers	46	23
	Oct.	Welded Design and Construction of Pressure Vessels and Pipework	46	14
	Oct.	Control of Distortion	46	10
	Oct.	Residual Stresses and Stress Relief	41	6
	Nov.	Welded Design and Construction in Aluminium Alloys	35	15
	Nov.	Welding in Shipbuilding	24	14
	Dec.	Inspection and Testing	45	12
1960	Jan.	Practical Ultrasonic Inspection	18	10
	Jan.	Resistance Welding	49	10
	Feb.	Welding for Junior Management	44	11
	Mar.	Inert-Gas Arc Welding	37	13
	Mar.	Welded Design and Construction in Corrosion- and Heat-Resisting Materials	26	15
17 day courses			660	222
			students	lecturers
		(average—39 per course)		
Evening Courses				
1959	E.1/6	Detail Design of Welded Structural Steelwork	65	9
1960	E.1/7	Detail Design of Welded Structural Steelwork	97	9
	E.2	Design for Welding in Heavy Engineering	131	11
			293	29
			students	lecturers

During the year, seven visits were arranged and four demonstration exhibitions were held. The School Committee, under the Chairmanship of Mr. E. Fuchs, is now giving consideration to the future development of the School after the end of the present programme in March 1961.

Awards

The Sir William J. Larke Medal of 1959 was awarded to Mr. C. A. Terry and Mr. E. A. Taylor for their paper on "*Welding of Cupro Nickel and Aluminium Bronze Alloys*", and the medal was presented to the winners at the Spring Meeting 1960, The following papers received special commendation:

A. A. Smith and P. T. Houldcroft: "*High Current Inert-Gas Metal-Arc Welding of Aluminium*", J. C. Borland and W. G. Hull: "*Manual 'Open-Air' Welding of Reactive Metals*".

The C. W. Hill Prize, which is now offered every third year, was in 1959 awarded to A. G. A. Cooksey, Associate, for his re-design for welding of a cast press bolster. A special second prize was awarded to A. L. Fishwick, Graduate, for the re-design of a bolted lattice girder. The design submitted by J. T. Allott, Associate, was highly commended.

Technical Committees

During the year, the Technical Committee carried out an extensive review of the Institute's representation at the British Standard Institution and resolved on a new procedure for maintaining closer liaison with the representatives.

The Inert-Gas Arc Welding Committee has proceeded with the preparation of the *Handbook on Inert-Gas Arc Welding* and the final draft is nearing completion. The Structural Committee has finished the draft of the booklet on the *Site Welding of Structural Steel in Building* and the Health and Safety Committee is revising the booklet on *Health and Safety in Welding*. in which new chapters on brazing, soldering and metal spraying will be included.

The new Committee on Metal Spraying met once during the year.

The Technical Committee and several of the specialized committees have been active in advising the British delegates and representatives to certain IIW Commissions and Sub-Commissions.

Library and Information Service

The growth in the use of the Service, referred to in the last Report, has continued throughout the year and much of the work of re-organisation has been completed. In July 1959, Miss P. E. W. Gray was appointed Assistant to the Librarian, Miss W. R. Urwin. The following is a record

of the use made of the Service during the year, figures of the previous year being in parentheses:

Loans: 1st April, 1959, to 31st March, 1960
Borrowers— 673 (481)
Items —1293 (1037)
Telephone enquiries: Average per week—53
IIW Abstracts: 171 (381)
Catalogue cards filed: 3546 (since July, 1959)

Branches

All Branches remained active throughout the year, and held full programmes of meetings, several of which were planned to interest in membership those engaged in special sections of the engineering industry. Mr. H. B. Merriman gave his paper on "*Welding and the Draughtsman*" to a large number of Branches during the year.

It was decided in principle to revive the annual one-day Conference of Branch Secretaries, which affords an excellent means of exchange of views and information among them, and between Branch Committees and Headquarters.

A new arrangement for the financing of the Indian Branch was agreed with the Branch Committee, and will come into effect from 1st April, 1960.

Co-operation with Other Bodies

The close co-operation with the British Welding Research Association, particularly in the management of the School of Welding Technology and the joint official organ, the *British Welding Journal*, showed no weakening, and was extended into other spheres of the Institute's work, particularly in the campaign for advanced education in welding, in the organization of the Conversazione on the work of the International Institute of Welding, and in the planning of a welding mission to the U.S.S.R., which it is hoped may take place in the summer of 1960.

The Conversazione emphasized the importance of the technical work of the International Institute of Welding, and also showed members of the Institute the advantages which it obtains for them by the secretarial services extended to the International Institute of Welding and the Joint Committee of the British member societies.

Membership

The Council approved a contract for the printing of a list of members, which will be offered for sale to members at a nominal price.

At 31st March, 1960, the total membership was 4,611, made up as follows:

Honorary Fellow	1
Patrons	12
Fellow	1
Honorary Members	12
Members	823
Associate-Members	1,811
Companions	184
Graduates	199
Associates	1,249
Industrial Corporate Members	
Class 1	301
Class 2	14
Class 3	4
	4,611

The increase during the year was 67, which compares with increases of 53 in 1958–59, 21 in 1957–58 and 89 in 1956–57.

The Council elected 260 (289) new members and approved 35 (64) transfers and 8 (4) reinstatements. During the year 89 (121) members resigned and 84 (95) were removed from the register by the Council for non-payment of subscriptions.

The Council records with regret the death, on 29th April, 1959, of Sir W. J. Larke, K.B.E., who was one of the two Honorary Fellows of the Institute, and the death, on 28th January, 1960, of Mr. A. C. Hartley, C.B.E., who was Vice-President of the Institute in 1958–59. The Council regrets to record also the death of 26 (24) other members.

The figures in brackets are the corresponding figures for the year 1958–59.

Premises

Much was done to improve the efficiency and attractiveness of the Institute's house, the necessary funds being drawn largely from the Furnishing and Mortgage Redemption Fund and the Appeal to Industry Fund. In the basement, a large room has been reconditioned for use as a refreshment room during School courses, and an attractive new office has been made for the School staff. Proper ventilating equipment has been installed in the Council Room, and about half the work needed to modernize the lift for institutional use was carried out. Improvements were made in the furnishing of the Library.

Plans have been drawn up which, over a period of four or five years, should complete the adaptation of the house and modernization of the Institute's equipment and furnishings. With the improving amenities goes a steady increase of the use made of the premises, and in particular of the Council Room, which has now to accommodate, beside meetings of the Council and its Committees, the School courses in alternate weeks, meetings of the Institute and of the two London Branches, and meetings of kindred institutions. The expanding programme of Institute meetings in the past two years illustrates the advantages of possessing a room large enough to accommodate a meeting of 100 to 150 people.

Finances

The Income of the year exceeded the Expenditure by £913, after providing £700 for depreciation of 54 Princes Gate and transferring £250 to the Mortgage Redemption Fund, which now stands at a figure sufficient to repay the outstanding £2,000 of the Mortgage loan on the Institute's premises. As compared with the previous year Income increased by £1,811 and Expenditure by £1,179, a reduction of £1,485 in the net Establishment Expenses being offset by increases of £1,988 and £677 in the cost of Direct Services to Members and Administrative Expenses respectively.

During the year contributions to the Services to Industry Fund totalled £1,538 and to the Furnishing and Mortgage Redemption Fund £345, and sums of £1,747 and £574 respectively were drawn from these Appeal Funds for improvements to the premises and furnishings.

Acknowledgments

At the close of another year of notable achievement, the Council offers its thanks to all who have assisted the Institute, and in particular to the subscribers to the two appeal funds, to the lecturers in the School of Welding Technology and to their employers, to the authors of papers presented at meetings, to the members of committees and sub-committees, to the honorary officers and committee members of the Branches, and finally to the staff, for loyal and efficient service.

THE INSTITUTE OF WELDING

BALANCE SHEET, 31st MARCH, 1960

31.3.59 £		£ s. d.	£ s. d.
	Accumulated Fund—		
	Balance as at 31st March, 1959	26,128 7 11	
	Add Excess of Income over Expenditure for the year	912 16 4	
26,128			27,041 4 3
	Provisions and Current Liabilities—		
600	Provision for Premises Repairs and Renewals	600 0 0	
600	Reserve for Publications	600 0 0	
7,980	Overdraft at Bankers (Secured by a charge on Investments)	7,352 13 1	
4,190	Sundry Creditors and Credit Balances	4,924 9 4	
382	Subscriptions, Entrance and Examination Fees received in advance	185 8 3	
13,752			13,662 10 8
	Loan on Mortgage (Secured by a charge on Freehold Property)		
	Balance as at 31st March, 1959	5,000 0 0	
	Less Amount repaid during year	3,000 0 0	
5,000			2,000 0 0
	British Welding Journal—		
2,997	Subscriptions in Advance		3,953 13 3
	School of Welding Technology—		
1,386	Fees and Deposits in Advance		554 14 10
	Appeal Funds—		
	"Services to Industry" Fund		
	Balance as at 31st March, 1959	7,245 17 8	
	Add Income for the year to 31st March, 1960	1,538 6 3	
		8,784 3 11	
	Less Expenditure on replacements and alterations to premises during the year	1,746 17 3	
7,246			7,037 6 8
	Furnishing and Mortgage Redemption Fund		
	Balance as at 31st March, 1959	252 5 7	
	Add Income for the year to 31st March, 1960	345 14 1	
		597 19 8	
	Less Cost of special furnishings and fittings purchased	573 17 9	
252			24 1 11
7,498			
	Special Funds—		
89	Sir William Larke Medal Fund	89 10 1	
287	C. W. Hill Prize Fund	272 5 3	
306	Life Membership Subscription Fund	325 19 3	
112	Tibbenham Trust Fund	118 10 9	
	Mortgage Redemption Sinking Fund—		
	Balance 31st March, 1959 £1,713 2 0		
	Add Income for year to 31st March, 1960—		
	Interest on Investments .. 33 7 0		
	Transfer from Income and Expenditure Account 250 0 0		
1,713		1,996 9 0	
2,507			2,802 14 4
£59,268			£57,076 5 11

31.3.59 £		£ s. d.	£ s. d.
	Fixed Assets—		
	Freehold Property, 54 Princes Gate, S.W.7, at cost	40,090 13 7	
	Less Depreciation written off	1,400 0 0	
39,391			38,690 13 7
	Note. An amount of £1,746 17*s* 3*d* has been expended during the year on replacements and alterations to premises which has been provided out of the Services to Industry Fund.		
	Furniture and Fittings at cost *less* Sales	4,173 5 6	
	Less Depreciation written off to date	1,402 16 5	
2,769			2,770 9 1
	Council Room Furniture at cost	409 4 6	
	Less Donations received	363 18 3	
45			45 6 3
	Special Furniture and Fittings at cost	1,620 2 11	
	Less Amount provided out of Furnishing and Mortgage Redemption Fund	1,620 2 11	
—			—
42,205			41,506 8 11
	Current Assets—		
1,306	Stock of Publications	490 4 6	
	Investments in Government Securities at		
6,222	cost (Market Value 31 Mar. 1960, £5,346)	6,221 16 8	
5,498	Sundry Debtors and Payments in Advance	5,157 8 8	
	Expenditure on Handbook for Welding		
611	Design—*less* Contribution and Sales	393 2 5	
	Cash at Bankers and in Hand, Head Office		
919	and Branches	504 10 5	
14,556			12,767 2 8
	Special Funds (*Investments and Cash at Bankers*)—		
89	Sir William Larke Medal Fund	89 10 1	
287	C. W. Hill Prize Fund	272 5 3	
306	Life Membership Subscription Fund	325 19 3	
112	Tibbenham Trust Fund	118 10 9	
	Mortgage Redemption Sinking Fund—		
	Investments in Government Securities at cost (Market Value 31st March, 1960, £708) £823 14 7		
	Cash at Bank £1,172 14 5		
1,713		1,996 9 0	
2,507			2,802 14 4
£59,268			£57,076 5 11

E. SEYMOUR-SEMPER, *President*

W. E. HARRISS, *Hon. Treasurer*

G. PARSLOE, *Secretary*

THE INSTITUTE OF WELDING

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31st MARCH, 1960

31.3.59 £		£ s. d.	£ s. d.
	Administrative Expenses—		
7,009	Salaries	7,731 16 4	
540	Superannuation	635 5 5	
200	Pension	200 0 0	
630	Travelling Expenses	868 6 8	
162	Entertaining	154 2 9	
1,379	Printing and Stationery	1,275 11 1	
661	Postages	663 9 6	
58	Sundry Expenses	86 4 10	
58	Legal and Professional Fees	35 14 0	
157	Audit Fee	157 10 0	
625	Interest on Mortgage and Bank Overdraft	347 11 9	
11,479			12,155 12 4
	Establishment Expenses—		
1,375	Rates, Lighting, Heating, Cleaning, Telephone, *less* Rents received	415 13 3	
1,211	Repairs and Decorations	680 6 5	
308	Depreciation (Furniture and Fittings)	312 17 10	
700	Depreciation (Property, 54 Princes Gate)	700 0 0	
250	Mortgage Redemption Sinking Fund	250 0 0	
3,844			2,358 17 6
	Direct Service to Members—		
1,598	Publications *less* Sales	2,787 0 1	
2,183	Library and Information Services	2,831 8 11	
2,366	Branch Expenditure	2,545 13 4	
405	Hire of Rooms and Meeting Expenses	324 8 5	
139	Examination Expenses	183 15 0	
283	Subscriptions to Scientific Societies	289 13 0	
6,974			8,961 18 9
281	Balance—Excess of Income over Expenditure, transferred to Accumulated Fund		912 16 4
£22,578			£24,389 4 11

31.3.59 £		£ s. d.
19,789	Subscriptions	19,663 6 8
607	Entrance Fees	658 12 7
136	Examination Fees	111 18 1
240	Interest Received	241 12 0
1,525	Contribution from International Institute of Welding	1,700 0 0
281	School of Welding Technology and Special Courses	2,013 15 7
£22,578		£24,389 4 11

REPORT OF THE AUDITORS TO THE MEMBERS OF THE INSTITUTE OF WELDING

We have obtained all the information and explanations which to the best of our knowledge and belief were necessary for the purpose of our Audit. In our opinion, proper books of account have been kept by the Institute so far as appears from our examination of those books. We have examined the above Balance Sheet and annexed Income and Expenditure Account which are in agreement with the books of account. In our opinion and to the best of our information and according to the explanations given us, the said Accounts give the information required by The Companies Act, 1948, in the manner so required, and the Balance Sheet gives a true and fair view of the state of affairs of the Institute as at 31st March, 1960, and the Income and Expenditure Account gives a true and fair view of the income and expenditure for the year ended on that date.

21 Godliman Street, London, E.C.4.
10th June, 1960.

GORDON EVANS & CO.,
Chartered Accountants.

Welding
TECHNOLOGY

INTERNATIONAL INSTITUTE OF WELDING

HOUDREMONT LECTURE – 1959

Hydrogen in Welding

A COMPARISON BETWEEN THE BEHAVIOUR OF WELDED, CAST, AND WROUGHT STEEL

By Professor Paul G. Bastien, D.SC., ING.E.C.P.

IT IS most touching that Commission IX of the International Institute of Welding has decided to found a 'Houdremont Lecture' in memory of its late Chairman, whose premature death has been so widely lamented.

Official references have been made to the titles of Professor Houdremont. He was a distinguished metallurgist, a former Director of Research at the Krupp works, and one of the most eminent authorities in the metallurgical world, more particularly with reference to steel; but I would like to stress his exceptional human qualities which made him a delightful and reliable friend.

I feel most fortunate and honoured to have been chosen to give the first Houdremont Lecture. We had been linked by bonds of friendship for several years, and, a short time before he was taken ill, we had spent a week together at the Research Laboratory of the Creusot works. There we discussed at great length the subject of hydrogen in steels, in which we were both deeply interested, and found with satisfaction that our views were identical. I am hoping therefore to pay tribute to the memory of Professor Houdremont by choosing for this paper the subject 'Hydrogen in Welding'.

IN THE following pages, I shall try to show how the knowledge gained concerning the effect of hydrogen in steel, mainly in forged or rolled steel, can be used to attempt to clarify the phenomena caused by this gas in welding. The experimental data gathered up to the present in this field are vast in quantity and often inconsistent, and I apologize in advance for the inevitably schematic character of a survey of a few pages. It will be based principally, but of course not exclusively, on the investigations begun twenty years ago and still in progress at the Research Centre for Metal Physics of the Ecole Centrale in Paris.

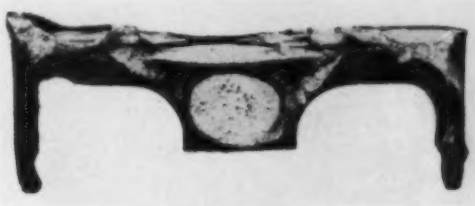
I shall adopt the following plan:

(*a*) Effects of hydrogen in wrought, cast, or welded steel; sources of this gas in the metal.
(*b*) Basic characteristics of hydrogen embrittlement.
(*c*) Tentative explanation of the mechanism of this phenomenon.
(*d*) Consequences in the field of welding.

Houdremont Lecture, delivered to Commission IX, 'Behaviour of Metals Subjected to Welding', at the 1959 Annual Assembly of the I.I.W., held at Opatija, Yugoslavia.

Dr. Bastein is Professor at the Central School of Arts and Manufactures in Paris, and Scientific Director of the Société des Forges et Ateliers du Creusot.

1—*Etched flakes on Ni–Cr–Mo steel forging blank*



2—*Flakes in a high strength Ni-Cr-Mo steel aeroplane structural member*

Effects of Hydrogen in Wrought, Cast or Welded Steel —sources of this gas in the metal

Effects of hydrogen

Wrought steel—In forged and wrought steels, and chiefly in special steels, there is now known to be a connection between the presence of hydrogen and the defects known as flakes, as well as certain fine cracks which are derived from these flakes.

On a machined and polished surface, flakes appear as very fine slits, which are made more visible by etching (Fig. 1). On fractured surfaces, they have a very special appearance: they look like spots of almost circular shape, lighter in colour than the normal surrounding fractured surface and with a different crystalline texture (Fig. 2). A refining heat treatment makes them considerably more visible. The dimensions of flakes are essentially variable, in the range of a few millimetres to a few centimetres.

Briefly summarized, the following points may be emphasized:

(i) The initiation of flakes requires, as Professor Houdremont[1] was the first to demonstrate, the presence of hydrogen in the metal. This fact has on several occasions given rise to controversy, but the positive results now obtained by vacuum casting of ingots up to 200 tons, with residual hydrogen contents of 2–3 p.p.m. only, leave no doubt as to the part played by hydrogen

(ii) The formation of flakes is a result of the combined actions of the hydrogen present and internal stresses, the increase of the latter promoting the initiation of the defects. This explains why, in a given steel, it is not easy to relate the frequency of the defect to a critical hydrogen level

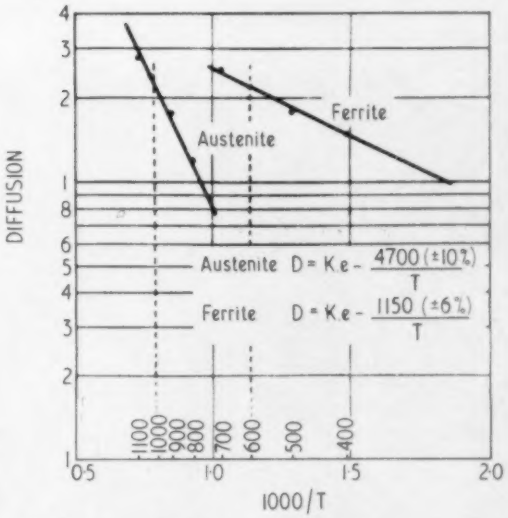
(iii) Special steels, notably the Ni–Cr and Ni–Cr–Mo steels, are particularly susceptible to it; nevertheless flakes may also be found in carbon steels

(iv) Austenitic steels can be considered as immune from flakes

(v) Flakes appear, during the cooling of thick wrought parts, at rather low temperatures; *e.g.*, below 300°C. Furthermore, the methods used to prevent their formation consist either of vacuum casting or of inducing sufficient hydrogen removal, by diffusion, by means of thermal cycles including prolonged periods at a temperature of approximately 600°C. (the optimum temperature for the diffusion of hydrogen in the α range) (Fig. 3), and reductions to 300°C. to achieve as complete a transformation as possible of the steel in the α range. This removal, by thermal means, of a portion of the hydrogen obviously becomes more difficult as the workpieces increase in size

(vi) As has been shown, more particularly by ultrasonic testing, flakes may appear in a steel part after an incubation period of several days: the phenomenon may, in a way, be 'delayed'

(vii) The association of flakes and inclusions has been pointed out by various authors, denied by others; it seems to me, however, that there is some evidence for it.[2] Nevertheless, it would be difficult to make an absolutely conclusive demonstration either way; inclusions in wrought steel are often only visible under a microscope, on a carefully polished section, whereas a flake of average size is 5–10 mm in diameter. It is therefore more than likely that the micrographic plane under examination will cross the flake without passing through the inclusion.



3—*Variation of diffusion coefficient with temperature*

Cast steel—Similar phenomena occur, though less frequently, in cast steel. Flakes and fine cracks due to hydrogen have been found in ingots and castings, but their appearance makes them less easily visible on fractured surfaces than on wrought and refined metal.

The less frequent occurrence of these phenomena seems to be connected with the following facts:

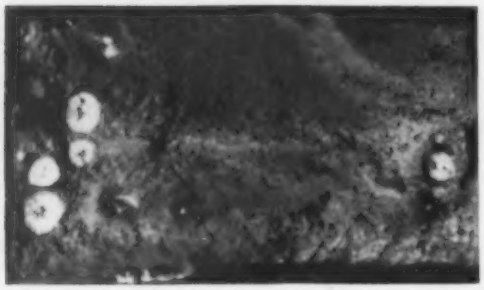
(i) In cast metal, a considerable portion of hydrogen passes in a molecular state into pores and micropores, with an equivalent reduction in the amount of hydrogen contained in the lattice, this amount being, as will be seen, the active part

(ii) The walls of cast productions are usually thin enough to allow diffusion of a considerable portion of the hydrogen towards the outside, during the relatively slow cooling in the mould

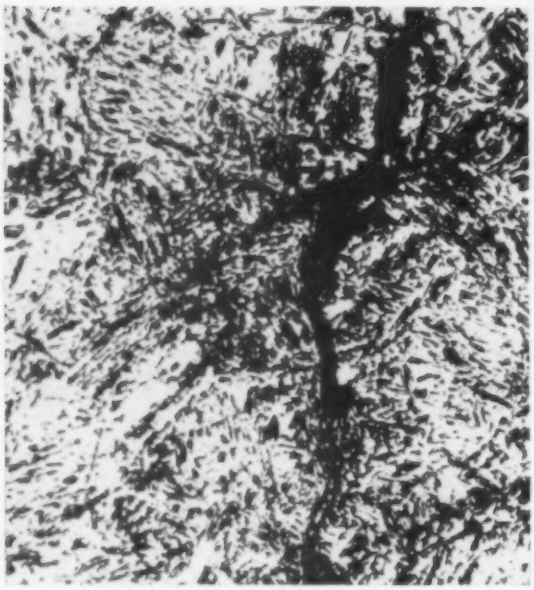
(iii) As regards ingots, they are seldom considered in this condition; they are generally not allowed, before forging or rolling, to be cooled to temperatures at which flakes are formed.

Welded steel—In welded steel, it is also certain that there is a connection between hydrogen and the formation of defects derived from flakes, fish-eyes, and cracks, which very often appear on a microscopic scale.

On fractured surfaces, fish-eyes appear, like flakes, as spots of almost circular shape, lighter in colour than



4—Appearance of fish-eyes in a weld



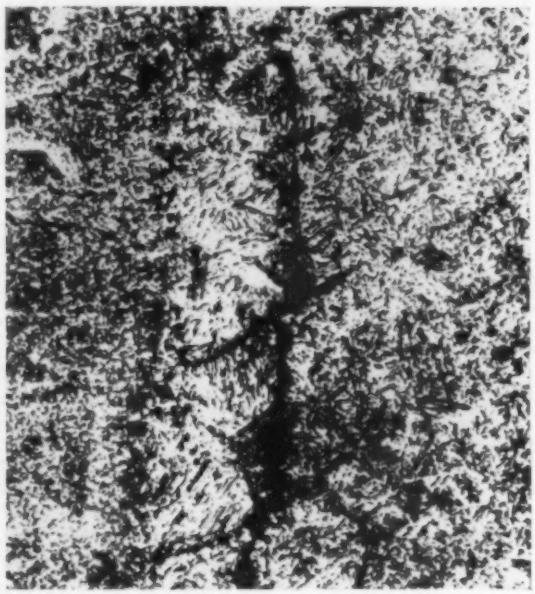
5—Underbead cracking in a type 54 Cr–Cu steel

the surrounding metal, but, unlike flakes, they are usually more or less centred on an inclusion or a pre-existing physical discontinuity which constitutes the 'eye' of the defect (Fig. 4).

Also, whereas the formation of flakes takes place under the action of internal stresses, and of course before the specimen or the part is broken, fish-eyes cannot appear unless the tensile yield strength has been exceeded, as shown by Erdmann-Jesnitzer and Kowalkowski.[3] Valanti[4] has, furthermore, shown, as a result of the application of ultrasonic testing, that this kind of defect is initiated only under maximum loading conditions and often just when reduction in area takes place.

As regards cracks, which are frequently on a microscopic scale and in the initiation of which the presence of hydrogen often plays an important part, they are located in the area altered by the thermal effect of the welding operation and are often designated as 'underbead cracking' (Figs. 5 and 6).

It seems advisable, in this connection, to distinguish between weldable low-carbon steels with added elements (Mn, Mo, Cr, ...) which raise their yield



6—Underbead cracking in a carbon steel (with defect in the parent plate)

strength, and weldable steels which contain carbon only (mild steels).

For the former, microcracks appear in a zone 0·2–1 mm thick which, under the thermal effect connected with the heat supplied and its rapid removal by conductivity, has developed into a more-or-less coarse martensitic or bainitic structure. It is probable that cracks may appear in this zone solely as a result of internal cooling stresses, although low-carbon martensites and bainites are remarkably ductile. It is nevertheless a fact that the hydrogen supplied, for example by electrodes with a high water content, notably increases the frequency of occurrence and the density of distribution of these cracks.

As regards weldable carbon steels (mild steels), microcracks, often in large numbers, may appear in the transition zone of welds, the phenomenon being more marked where the electrodes used are more likely to add hydrogen (non-basic coatings or insufficiently dried basic coatings) and where a higher level of internal stresses may be set up (thick plates, cold welding). In this case, hydrogen acts as an *essential embrittling agent*.

Sources of hydrogen in the metal

Hydrogen cannot get into the iron, in liquid or solid form, in a molecular state, and the gas must previously pass to an atomic or ionic state before diffusion following adsorption. The best known cases of this passage to the atomic state are as follows:

Dissociation of molecular hydrogen in contact with iron

Whereas at low temperature (below −100°C.), hydrogen is fixed in a molecular state on the iron by physical adsorption, adsorption is activated at higher temperatures and the dissociation:

$$H_2 \rightleftharpoons 2H$$

occurs at the surface of the adsorbing material, the atoms of hydrogen being fixed by intervention of the primary valencies.

Adsorption, an exothermic phenomenon, decreases when the temperature rises so that, in the high-temperature range (above 1000°C. for instance), the concentration of hydrogen in the adsorbed layer is low, and a long period is necessary before a considerable quantity of hydrogen can penetrate the iron when a pure and dry gas is used.

Dissociation of a hydrogeneous compound and, more particularly water vapour

A gaseous compound *AmBn* is dissolved in a metal after dissociation into its constituent atoms, and the variation of solubility S as related to pressure p takes the following form:

$$S = f\left(\frac{I}{p^{\frac{1}{m+n}}}\right)$$

The equilibrium between gaseous compounds and molten metals has been studied in some cases, more particularly in that of water vapour and iron, by Chipman and Fontana,[5] Chipman and Samarin,[6] Erlich,[7] and this has made it possible to measure the equilibrium constants.

Among all the causes of the introduction of hydrogen in steels, the dissociation of water vapour is by far the most important, for water may come from numerous sources, more-or-less easy to discover and fight. In the case of welding, the coating plays a large part, either through the dissociation of organic compounds (cellulosic substances, for example), or through the presence of combined water or moisture which, decomposed under the effect of temperature and, possibly, catalytic actions (presence of iron powder in the coating, for example) liberate atomic hydrogen. The moisture of the air may also play a part, either by the hygroscopic effect of certain components of the coatings, or even directly.

Chemical or electrolytic reaction liberating atomic hydrogen in contact with the metal

Any chemical or electrolytic reaction liberating atomic hydrogen, activated or ionized, on the surface of iron or of a steel, causes the penetration into the metal of a volume of gas which may be considerable.

This happens more particularly in the case of attack in an aqueous acid medium and in that of the electrolytic dissociation of water, iron being at the cathode. This explains, in particular, accidents due to hydrogen which take place during pickling and electrolytic deposition, and, in natural gas fields, in the exploitation of strata containing most hydrogen sulphide (Lacq).[8]

The electrolytic charging of mechanical test specimens constitutes, as will be seen, a convenient and precise means of studying the embrittling effect of hydrogen.

Basic Characteristics of Hydrogen Embrittlement

Among the various mechanical characteristics obtained by the conventional tensile test, the absorption of hydrogen affects only the elongation at failure and, more especially, the reduction in area, both of these being reduced. The behaviour of a steel in relation to hydrogen absorption can therefore be shown very clearly by the variation in the reduction in area, or, better still, by the embrittlement index:

$$I(\%) = \frac{\Sigma u.c - \Sigma c}{\Sigma u.c} \times 100,$$

where $\Sigma u.c$ is the reduction in area of steel free from hydrogen, and Σc that of steel charged with hydrogen.

The elongation at failure, $A\%$, is a less suitable characteristic, since it is the result of a localized elongation and a distributed elongation, the latter being very little affected by hydrogen.

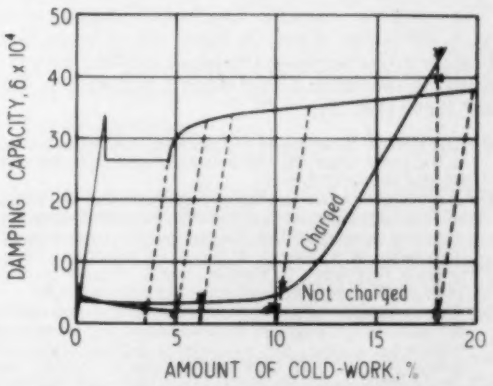
Hydrogen absorption does not cause much variation in the mechanical strength characteristics, as given by the conventional tensile test.

A special feature of the effect of hydrogen on the deformability of annealed steel (as shown by reduction in area or by a number of reversed bends) is its provisional character; at ambient temperature the deformability increases gradually as the gas leaves the metal, and it will return to its initial value provided that the original hydrogen absorption has been sufficiently gradual and controlled not to give rise to any actual deterioration of the metal (blisters, blowholes, cracks, or microcracks). At ordinary temperatures, hydrogen leaves the metal at a rate which increases with each of the following media in the order shown: dry air, moist air, water containing traces of Na_2S, pure water;[9] the rate is appreciably more rapid at 100°C., especially in boiling water, and advantage is taken of this in wire drawing. This influence of the medium around the charged sample seems to be connected with the hydrogen concentration in the adsorption film, at the surface of the metal.[9,10]

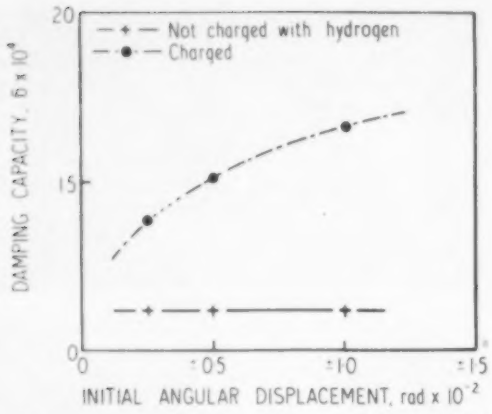
Effect of hydrogen in the range of elastic deformations

The foregoing considerations suggest that the effect of hydrogen is either very limited or non-existent over the range of elastic deformations, and becomes important in the case of plastic deformations, especially when triaxial stresses are being built up (for instance, as the area is reduced in the case of a tensile test).

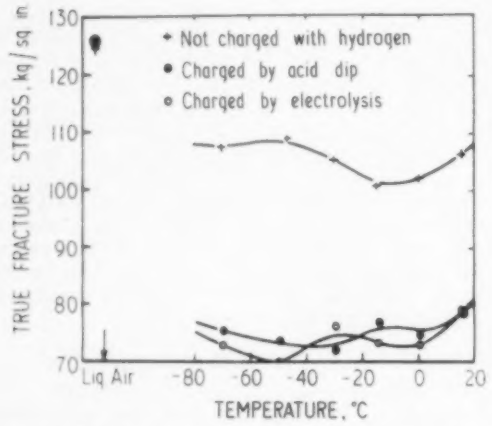
It has been possible to obtain accurate information, by using the very sensitive method of damping capacity measurement. This has been done by the



7—*Results of internal damping tests using the Cabarat apparatus*



8—*Results of internal damping tests using a Coulomb torsion micro-pendulum*



9—*Variation of true failure stress with test temperature*

determination of damping for very small stresses and also for appreciable stresses.

In the first case, damping capacity was measured on test bars of annealed iron, with or without electrolytic charging, which had been strained by various amounts of cold working.

The results were obtained with the Cabarat apparatus, in which the sample is subjected to longitudinal vibration with a very low amplitude so that the stresses induced in the metal do not exceed 20 g/sq.mm. They show that[11] (Fig. 7):

(*a*) The internal damping of charged and uncharged test bars is the same when the vibrations do not stress the metal beyond the yield strength

(*b*) A modification due to hydrogen appears when the amount of cold-working exceeds about 8%; beyond that value the damping capacity of the charged metal increases quickly. This value of 8% seems to me to be important, since it appears very often in different kinds of tests invoiving both cold-working of iron and steel and hydrogen

(*c*) When a sample is charged with hydrogen and cold worked, for instance to 18%, and then maintained at room temperature for a long time, its damping capacity drops progressively and comes back to the damping capacity value of a similar sample uncharged with hydrogen but otherwise subjected to the same amount of cold-work.

This point is important: the change in damping capacity is thus reversible and is not caused by the formation of macro- or micro-cracks inside the metal.

The damping capacity of charged and uncharged test pieces was also measured for appreciable internal stresses, with a Coulomb torsion micropendulum. In varying the initial angular displacement, a certain number of crystals, depending on the initial amplitude but in any case quite large, penetrate into the plastic region of deformation in the course of the test.

The results obtained[11] show that, in steel subjected to hydrogen charging, the damping capacity increases with the initial torsional displacement, and it seems possible to conclude that, for an extremely small initial displacement, the damping capacity in the charged and uncharged condition is the same; a conclusion that is in good agreement with the previous results (Fig. 8).

All this confirms that *the effect of hydrogen in the elastic range is small or non-existent.*

Influence of hydrogen in the range of plastic deformations

Taking in general the reduction in area as the criterion for the effect of hydrogen in iron and steel, for the reasons outlined above, the following points have been studied successively:

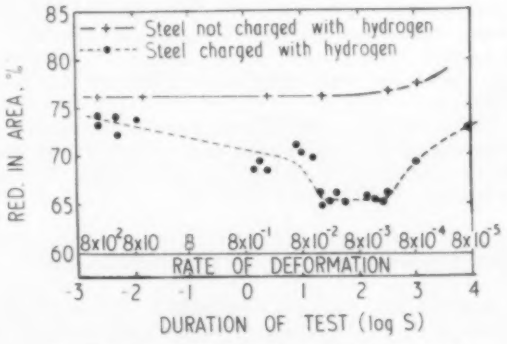
(*a*) Effect of test temperature
(*b*) Effect of speed of testing
(*c*) Effect of rest period after hydrogen charging.

Effect of test temperature

Embrittlement due to hydrogen does not appear at all temperatures. In this connection it is particularly interesting to study how the true failure stress (the ratio between the load applied to the test bar at fracture and the minimum cross-sectional area at that moment) and the reduction in area vary with the temperature.

The results obtained (Fig. 9) show that, at room temperature for instance, the true failure stress is, without any doubt, very much lower as a result of hydrogen charging. On the contrary, at very low temperatures, in liquid air for example, hydrogen embrittlement disappears, despite the fact that hydrogen remains inside the metal, as is shown by the reversible reappearance of the embrittlement on returning to ambient temperature.

When the test temperature is increased above room temperature, hydrogen embrittlement slowly



10—*Variation of reduction in area with test speed*

disappears, mainly because the hydrogen is slowly escaping from the test piece.

Briefly, it is in the range around room temperature that hydrogen embrittlement is at its maximum.

These experimental results have since been confirmed.[12]

Effect of the rate of plastic deformation (speed of testing)

Comparisons have been made for various rates of loading, during tensile tests, of the values of the reduction in area obtained on uncharged test bars and on samples subjected to a 48 hr electrolytic charging.

Hydrogen embrittlement disappears for very fast tests; it has a maximum value in the range of usual rates of plastic deformation, corresponding to the conventional static tests (Fig. 10). For very slow deformations the experimental results are not so clear, because the reduction in area becomes more marked both in charged and uncharged material; however, the disappearance of embrittlement will definitely occur at the limit, owing to the gradual removal of the gas from the metal in the case of extremely slow tests, under the influence of time and plastic deformation.

These experimental results have since been confirmed.[13]

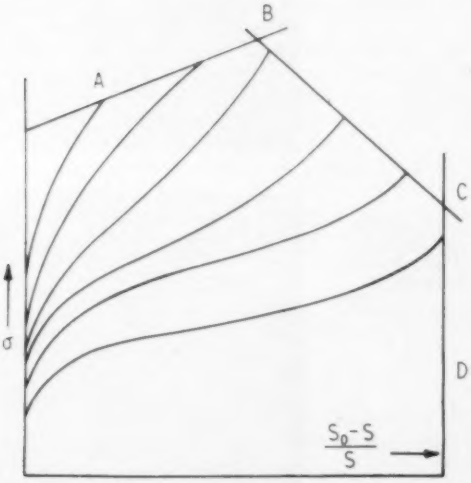
Effect of rest period after hydrogen charging

Using a very carefully controlled method of charging, we have investigated, with Dr. P. Azou and Dr. J. Plusquellec, the influence of the time of charging and the ensuing rest period.[14]

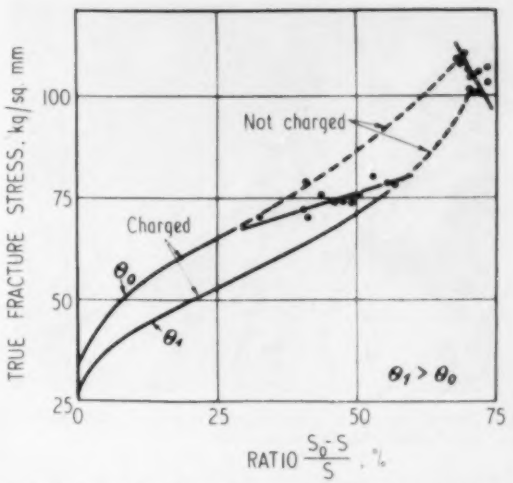
Generally speaking, as is well known:

(*a*) The reduction in area is generally reduced as the time of hydrogen charging is increased, and
(*b*) The hydrogen embrittlement is less marked as the rest period at room temperature increases.

But there are, on the surface representing the reduction in area against the time of charging and the rest period, several anomalies which are being carefully studied; similarly, the quantity of hydroger introduced in iron and steel, for a given total time of charging, is much greater if the treatment is carried out intermittently, with rest periods, than if it is carried out continuously.[14]



11—*Variation of true stress σ with relative variation of test piece section* $(S_0-S)/S$ *at different temperatures*



12—*Variation of true fracture stress, at different temperatures, with* $(S_0-S)/S$ *for test pieces charged and uncharged with hydrogen*

We have intentionally summarized these recent results, since they show clearly the great complexity of the mechanism which is covered by the term 'hydrogen embrittlement'.

Influence of hydrogen on the shape of the tensile curve of a given steel

The surface of fracture of a sample of an extra-mild plain carbon steel (C=0·07%) in a tensile test exhibits two distinct zones:

(*a*) A central circular area which is granular and bright, and
(*b*) A grey annular area which is fibrous and has the shape of a truncated cone.

The first corresponds to fracture in a brittle manner and the second to fracture by slipping.

The effect of hydrogen charging is to increase the relative area of the central zone, which breaks in a brittle manner. This fact can be studied more accurately in the following way. On investigating the true stress σ, in a tensile test, as a function of the relative deformation $(S_0-S)/S$ at different temperatures (S_0= initial cross-sectional area; S=area at the instant of measurement), it is possible to distinguish, according to Ludwik[15] and also Shevandin[16], three separate sections of the diagram (Fig. 11):

AB—brittle fracture,
BC—semi-brittle fracture,
CD—ductile failure.

Applying this, under similar conditions, either to an uncharged extra-mild steel or to the same steel electrolytically charged, we obtained results (Fig. 12), which show that the uncharged steel exhibits *semi-brittle fracture*, while the hydrogen charged steel failed under *brittle conditions*, within the temperature range covered by our tests (−110°C. +15°C.).[17,18]

Electro-microfractography confirms this, by showing that the hydrogen charging of a mild steel gives rise to a distinct increase in the number of areas which

13—*Tensile test piece charged with hydrogen. Electron-micrograph illustrating brittle fracture*

14—*Tensile test piece not charged with hydrogen. Electron-micrograph illustrating ductile fracture*

break in a brittle manner (Fig. 13) to the detriment of those which break in a ductile manner (Fig. 14).

Effect of the microstructure on the hydrogen embrittlement of a given steel

Preliminary experiments have shown that the hydrogen embrittlement of a given steel, for a particular hydrogen charging, depends greatly on its structure. With Dr. P. Amiot,[19] we chose for our experiments in 1952 a Cr–Mo steel having the following composition:

$$C=0{\cdot}26\%;\ Cr=1{\cdot}2\%;\ Mo=0{\cdot}30\%$$

which, by means of suitable heat treatment, can be made to exhibit the whole range of microstructures obtainable with an alpha steel.

In these different structural conditions, the test bars were subjected to the same hydrogen charging, and the results were analysed by using the embrittlement index:

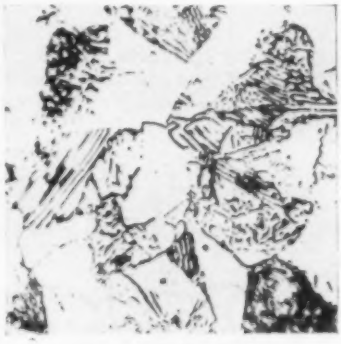
$$\frac{\Sigma u.c-\Sigma c}{\Sigma u.c}\times 100$$

Briefly summarized, the results obtained[19] were as follows:

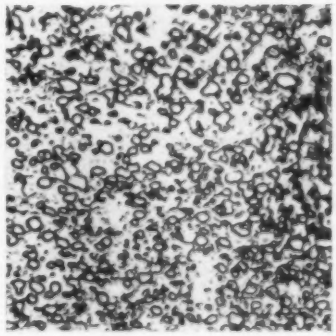
All other things being equal, the hydrogen embrittlement of a steel is closely related to its structure and can vary between wide limits (Figs. 15, 16 and 17). The structures obtained at the highest temperatures and in a state as near as possible to thermodynamic equilibrium are least susceptible to the action of the hydrogen; these are at the same time the most plastic structures. Thus, structures consisting of pearlite or fine spheroidal sorbite are least affected, whilst martensitic structures, as is well known, are those most susceptible to hydrogen embrittlement. Under similar experimental conditions the fine spheroidized structures also absorb a smaller amount of hydrogen than martensite and possess a higher diffusivity.

The values shown in Table I were obtained at ambient temperature on the Cr–Mo steel investigated.

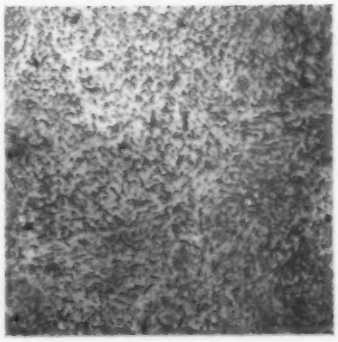
These results have been supplemented by delayed failure tests under constant load, carried out on test bars charged with hydrogen before being subjected to mechanical loading, and maintained under cathodic electrolysis throughout the test. For structures with fine spheroidal carbides the values of the stresses



15—*Structure with lamellar carbides (pearlite)* ×1000



16—*Structure with dispersed and relatively large globular carbides* ×1000



17—*Structure with very fine and dispersed globular carbides* ×1000

causing delayed failure are practically equal to the corresponding yield strengths; in the case of thermodynamically less stable structures, on the other hand, the values are much lower than the yield strength.[21]

Location of hydrogen in the lattice of iron and role of crystalline imperfections

The experimental evidence suggests that hydrogen diffuses into metals in the atomic state and that this absorption is a lattice process, taking place in an interstitial manner.

Table I

Effect of microstructure on the embrittlement index (Cr–Mo steel)

Structure	*E, kg/sq.mm*	*Embrittlemen Index, %*
Spheroidal pearlite*	54	31†
Lamellar pearlite	51	39
Coarse lamellar pearlite	35·5	42
Martensite	122	100
Martensite tempered at 500°C.	103	94

* Fine spheroidal pearlite, obtained by the following treatment: austenization for 30 min at 875°C., oil quenching, spheroidization by means of 3 cycles consisting of 15 min at 750°C. and 30 min at 680°C.

† Steels, having delayed tempering, heat-treated to have a very fine spheroidized structure, in the range of a yield strength of 81,000–94,000 lb/sq.in. (56–65 kg/sq.mm), have been developed in France on this basis and have now been in use successfully, for two years, for the exploitation of the natural gas fields near Lacq.[20]

In the case of hydrogen and iron, the hydrogen in the metal lattice is most likely to be in the form of protons H^+, with a positive electrostatic charge. However, these considerations do not show whether there is any preferential location of the protons and provide no indication of the part played by crystalline imperfections.

By X-ray diffraction experiments, we have been able, with Dr. P. Azou and Dr. J. Plusquellec, to show[22] that hydrogen charging causes a clear distortion of the planes 112, though such distortion disappears after heating in vacuum at temperatures too low to induce any restoration of the iron lattice.

This experimental fact and some other theoretical considerations have led us to the conclusion that there is a tendency for hydrogen to collect in the 112 planes and probably in the defects on the alpha iron lattice in this system of crystallographic planes.[23]

Such a location provides an explanation for the following facts:

(*a*) Absence of hydrogen embrittlement in metals and alloys in which the 112 planes are not active slip planes

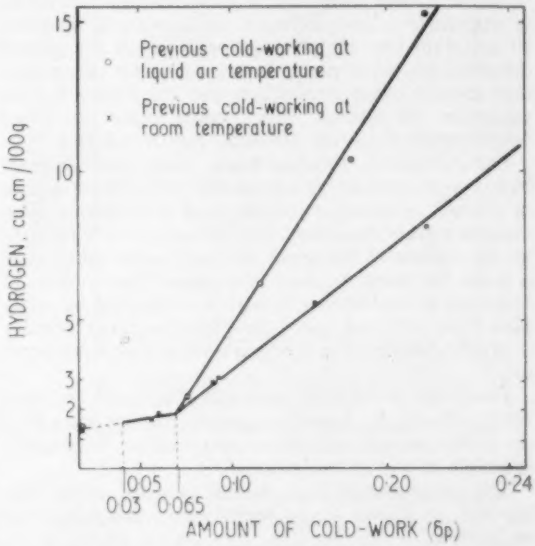
(*b*) Disappearance of hydrogen embrittlement in alpha iron at low temperatures, where the 112 planes are no longer active in slipping

(*c*) Increase in the damping capacity with cold-working more than about 8%, a value which is necessary to initiation slipping along the 112 planes.

Effect of crystalline imperfections

Numerous experimental measurements have shown that an amount of hydrogen much greater than that contained in a saturated solution may be introduced into iron and steel. The amount is greatly increased by cold working the metal.

This leads logically to the conclusion that voids of various types in the crystal must play an essential part. In recent experiments,[24] we have obtained results giving the quantity of hydrogen introduced at room temperature, by means of the same electrolytic charging, in a given extra-mild steel after cold-working obtained by straining the metal several times at room temperature or in liquid air (Fig. 18).



18—*Quantities of hydrogen extracted after charging as a function of previous cold-working. (The curve between 0·00 and 0·03 is extrapolated, owing to the impossibility of obtaining, in this field, regular deformation)*

After cold-working in liquid air, it is possible to introduce much more hydrogen into the metal than after the same amount of cold-working at room temperature, above a straining of 8%. In the first case (liquid air), plastic deformation occurs by twinning along the planes 112; in the second case (room temperature), by slipping along the planes 112. The voids must be greater in the first case than in the second.

This leads logically to the conclusion that the voids in a crystal must play an essential part. As far as the proton is concerned, the variation in potential produced by these defects will determine a preferential location. Most workers agree on the assumption that the hydrogen is segregated in these defects. The actual form taken by this hydrogen will then depend on the size of the defect; it may exist as protons in the smallest defects (vacancies and dislocations), as atoms or even molecules in medium-size defects (piles of dislocations, substructure joints and grain boundaries) and certainly in molecular form in blow-holes, blisters and cracks.

Tentative Explanation of the Mechanism of Hydrogen Embrittlement

In view of this uncertainty regarding the values of the binding energies, as well as the actual state of the hydrogen in the iron lattice (especially in its defects),

it is quite clear that at present one can only speak of 'possible' mechanisms.

Zapffe's theory,[25] the planar pressure theory, states that the molecular hydrogen can segregate in the voids of the lattice and create pressures sufficiently large to produce premature failures. During plastic deformations these voids increase in size and the pressure drops giving rise to a fresh diffusion towards the voids so as to maintain the 'embrittling' pressure. If the plastic deformation takes place too rapidly, this compensation cannot come into effect, and the embrittlement decreases. A similar effect takes place at lower temperatures since the diffusion rate is reduced.

On an entirely different basis, Petch and Stables[26] have suggested that a failure results from the formation of a crack ahead of a collection of dislocations piled up near a grain boundary. The adsorption of hydrogen on the surface of this crack liberates some energy and reduces the stress required for failure. The amount of hydrogen adsorbed in this way is controlled by diffusion, thus involving again the effect due to an increase in plastic deformation rate and a reduction in temperature.

Using rather different basic considerations, we have proposed with P. Azou[27] a possible mechanism which up to the present has served very well as the guiding principle in our investigations.

The experimental facts which must be taken into account, as shown at the beginning of this paper, are as follows:

(*a*) The effect of hydrogen in iron and steel is not noticeable in the elastic range
(*b*) In the plastic range it produces an embrittlement which disappears at high deformation rates and at low temperatures
(*c*) The mechanism proposed must be compatible with the preferential location of the hydrogen in the 112 planes.

The fact that hydrogen has no perceptible effects in the elastic region leads to the following conclusions:

Firstly, that hydrogen does not produce the effects generally found when an element forms a solid solution in iron. If it produces a preferential distortion of the 112 planes, it does not give rise to an appreciable change in the lattice parameter, as shown by the accurate measurements performed by several workers, among them Wever and Lehrmann,[28] Wever and Pfarr,[29] Portevin, Chaudron and Moreau.[30]

Secondly, that it is necessary to revise the concept of the classic 'planar pressure theory', *viz.* that hydrogen atoms segregate in the voids, transform themselves into molecular hydrogen and create high pressures and thus appreciable triaxial stresses in the surrounding metal. Such internal stresses should have been shown up by the internal friction tests using very low stresses. We are therefore led logically to the assumption that, at the thermodynamic equilibrium, the number of hydrogen atoms passing per unit area and unit time from the lattice into the voids is equal to the number passing in the reverse direction from the voids to the lattice. By analogy with a macroscopic wall which receives an equal number of impacts and therefore an equal quantity of momenta from either side, such a condition must lead to a state of mechanical equilibrium at the wall and not to the effect of a resultant force producing triaxial stresses.

We are therefore led to believe that it is *the disturbance of the balance due to the influx of hydrogen atoms into the voids* during plastic deformations, which produces the triaxial stresses in the surrounding metal and correspondingly reduces the deformability.

With P. Azou, we put forward in 1950, on this basis, the following mechanism:[27]

The hydrogen in the metal has a tendency to become concentrated in zones of maximum free energy, that is to say, in all the irregularities of the lattice, such as vacancies, dislocations and groups of dislocations, remaining in the ionized state if the electrostatic field is sufficiently strong, and collecting in the atomic and even molecular form if the crystalline irregularity is sufficiently large. From a consideration of the interaction between the dislocations and the protons, one can expect a considerable difference in behaviour with carbon and nitrogen owing to the much greater mobility of the proton, and this despite a relatively low proton-dislocation binding energy. The protons can thus be carried along by the movement of the dislocations during plastic deformation, and this may then produce in the structural defects, against which the dislocation piles up, *a local and temporary oversaturation of hydrogen*, followed by an increase in pressure which produces triaxial stresses and embrittlement in the metal around the crystalline voids or the cracks formed or enlarged by cold working.

For this it is necessary that the protons should be able to accompany the dislocations during their movement. It is therefore necessary that the proton diffusion rate should be greater than, or equal to, the rate of movement of the dislocation. It follows that the test temperature must not be too low or the rate of plastic deformation too great.

Furthermore, because of the preferential location of hydrogen atoms in the 112 planes, one is led to assume that the hydrogen tends to collect in the defects associated with these planes and probably in and around the dislocations related to this system. This provides the explanation why there is no embrittlement at ordinary temperature in metals in which the 112 planes are not active slip planes.

At the present time, this schematic mechanism must of course be taken only as a tentative explanation, despite the supporting experimental evidence. Nevertheless, it is capable of explaining the occurrence of delayed failures in the presence of hydrogen for stress levels well below the yield strength. The most unstable dislocations, those which come into play especially during the phenomena of damping and fatigue, can be set into motion by such stresses: the mechanism by which the protons are carried along and by which the pressure is increased at groups of piled-up dislocations may thus give rise to the development of micro-cracks ahead of these groups.

Consequences in Welding

It appears evident from the foregoing considerations that the production in steel of defects of the sharp notch type which are under consideration (cracks, flakes, fish-eyes) is a result of the *simultaneous* effect of hydrogen and mechanical stresses in the metal. This type of defect is extremely dangerous, for it gives rise in service to local concentrations of stress which are often high: we will therefore consider such defects in this section and try to find out what may be the effects

of our present knowledge of hydrogen embrittlement in the field of welding.

To begin with, we will briefly recall the part played by hydrogen in the formation of internally growing blowholes and porosity. Hydrogen may be at the origin of blow-holes of this type, which are due to dissolved gases and result from the sudden decrease of gas solubility when solidification occurs. As regards cast steel and cast iron, the extensive development in steel laboratories of gas content determination techniques has often made it possible to specify the safe limit for a given fabrication. Portevin,[31] for instance, has pointed out that regular control of the hydrogen content in the production by the open-hearth process of 4–6 % chromium steels showed that there were regular casting surges for contents of 9–10 p.p.m., whereas contents below 7·5 p.p.m. gave complete safety. In the same way, Hurst and Riley[32] have found, as a result of systematic determinations by vacuum melting, that in sound castings of silicon cast iron the hydrogen should not exceed if possible 2 p.p.m. This limit of 2 p.p.m. for hydrogen seems to be found also in the properly controlled fabrication of cast iron mill rolls.[33]

It must be added that hydrogen is certainly not the only gas responsible for the presence of blow-holes, and that oxygen may act in conjunction with it through the formation of reaction carbon monoxide. This, added to the fact that gas releases depend on all the factors which affect the production or the suspension of out-of-equilibrium conditions (cooling rate, presence or absence of nuclei, . . .) explains why it is impossible to specify a dangerous hydrogen content and that, for a given fabrication, an indication only can be given of the safety range within which the content should as far as possible be maintained. The rapid solidification of the metal in welding is an advantage which results in a less frequent formation of blowholes than in steel melting.

Returning to notch-type defects, we are necessarily led by the foregoing considerations to study the simultaneous effect of hydrogen and stresses.

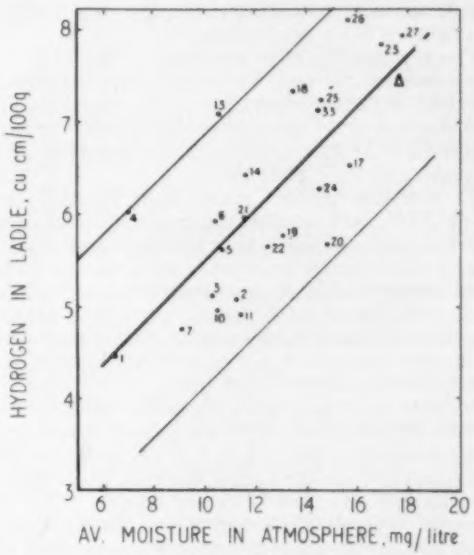
As the introduction of hydrogen in liquid steel is essentially due to the formation of atomic hydrogen through the dissociation of hydrogeneous compounds, particularly water vapour, every effort is made in steelmaking to prevent the introduction into the furnaces of damp scrap iron, ferro-alloys with large hydrogen contents, damp lime or fluorspar, water, or water vapour from leaks in the water-cooled doors.

The part played by the humidity of the air is not so well known.[33]

In the case of acid steels produced by the open-hearth process, Ferry and Guenot, of the Creusot works, have managed to obtain, by means of a statistical study of twenty-three casts, a good correlation between the hydrogen content of the cast metal and the average humidity of the atmosphere during refining (estimated correlation coefficient $=0{\cdot}70$). The equation of the straight correlation line Δ is:

$$H_4(\text{cu.cm/100 g}) = 0{\cdot}278 \times \text{water content (mg/l)} + 2{\cdot}71$$

This effect of humidity is relatively large, as shown by the slope of the straight line (Fig. 19): in the case of a saturated atmosphere (relative humidity=1) the average hydrogen content of the steel will be 4·6 cu.cm/100 g for an ambient temperature of $\theta_{\text{average}}=5°\text{C.}$, and it will reach 7·5 cu.cm/100 g for $\theta_{\text{average}}=20°\text{C.}$



19—*Relationship between air humidity and hydrogen content of steel*

In welding, without dwelling on well-known matters, it will be recalled that the frequency of occurrence of defects of the micro-crack and fish-eye type is connected with the water content, or more precisely the 'potential hydrogen' content of electrode coatings, that crystallization water and simply adsorbed water are definitely associated with the coating material, and that industrial baking operations are often insufficient to achieve complete elimination; this seems to be more frequent in the case of extruded basic electrodes than in that of dipped electrodes, owing to the high crystallization water content of the materials generally used to improve the extrusion properties of the paste.

The direct effect of the humidity of the atmosphere, through the dissociation of water vapour in the arc, on the introduction of hydrogen in welding is more difficult to define on a statistical basis than in steelworks, whereas its indirect effect through reaction on the hygroscopic products of coatings is certain. We may however quote our personal experience of the construction of a penstock in which, *all welding conditions being exactly the same*, welds made outside showed no defects while many were to be found in those made under cover in an atmosphere saturated with water vapour (micro-cracks and fish-eyes).

Hydrogen having thus been introduced into the steel, for example in contents of approximately 3–6 p.p.m. which are quite sufficient to give rise to embrittlement phenomena, these will be severe and occur after a very short time where there are stress levels inducing local plastic deformations accompanied by slipping along the 112 planes, or belatedly where the stress levels are below the yield strength (delayed fracture).

The direction of local stresses and their degree of triaxiality play a part: the development in hydrogen-embrittled metal of cracks, originating from micro-cracks which are at present believed to form ahead of piled-up dislocations, will be facilitated by local

tensile stresses, and to an increasing degree as their triaxiality is more pronounced.

Cooling speeds, after one pass of welding, *for a given steel and a given welding operation*, will depend on the thickness and temperature of the plates; the value and distribution of these speeds will govern the nature and level of the stresses, their triaxial character usually increasing with the plate thickness.

In weldable carbon steels, high cooling speeds below 300°C. will facilitate the development of stresses in a temperature range where hydrogen embrittlement clearly occurs under the effect of static stresses. In high yield strength weldable steels there will also be formed under the effect of these high cooling speeds, in transition zones, martensitic or bainitic border lines which, as already mentioned, are particularly susceptible to the embrittling effect of hydrogen.

In both cases, preheating the plates before welding will be advantageous, as it will reduce speeds in the latter stages of cooling; that is to say in the temperature ranges which are dangerous from the standpoint of hydrogen. Furthermore, as regards high yield strength weldable steels, the use or development of steels containing special elements, proportioned in such a way as to limit their hardenability and facilitate higher transformations or to raise the temperatures of the bainitic transformations, is bringing or will bring about an improvement with respect to defects due to hydrogen.

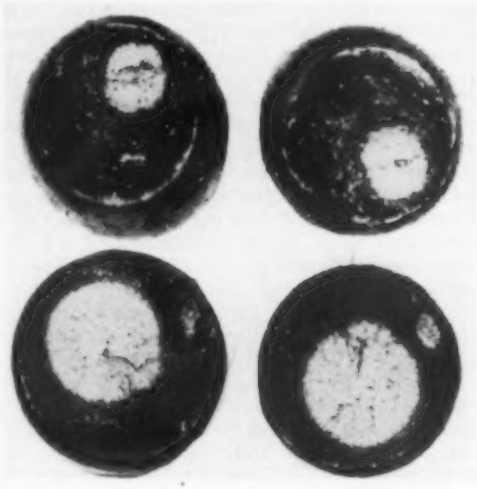
When the combined effects of hydrogen content and cooling stresses are insufficient to give rise to cracks, the presence of hydrogen in the metal is nevertheless sufficient to lower the capacity for deformation, more particularly reduction in area, this decline being progressively attenuated with time as hydrogen spontaneously escapes from the metal. There again, welding on preheated plates, by slowing down the cooling operation, facilitates the diffusion of the gas towards the exterior.

With dynamic loads, it has now been clearly demonstrated that, if impact tests are performed on annealed steel, charged with hydrogen, there is no sign of the embrittling effect of the gas, for the protons cannot follow the too rapid movements of the dislocations. In welding, the position may be different, as Moneyron and Séférian[34] have shown, for welding stresses may be high enough to give rise to the embrittlement of the metal, before the plastic deformations due to the mechanical test, and in this case the impact test shows that the fracture energy is lower.

Many queries however remain to be answered in the field of hydrogen embrittlement. Only two will be mentioned:

(i) *Flakes and fish-eyes*—The circular or elliptical shape of flakes and fish-eyes suggests that they have a common origin, which might be the local segregation of hydrogen that, in the case of fish-eyes, may result from the small pearl of coating slag often evident in the centre of the defect. However, why do flakes appear in the workpiece spontaneously, either immediately or after an incubation period, whereas the production of fish-eyes requires, if not failure, at least important hetrogeneous plastic distortions? This difference has not been clearly explained so far, but it may be pointed out that the special steels used in forging and rolling are different from weldable steels, and that they have in particular a higher hardenability. The wall thicknesses involved are also generally, very different.

It is, moreover, possible to obtain defects, having the appearance of fish-eyes, on broken tensile specimens of steel charged with hydrogen by acid etching or by electrolysis (Fig. 20).



20—*Fish-eyes in tensile test pieces of extra-mild steel charged with hydrogen*

(ii) *Immunization of welds against micro-cracks by hardening*—According to various authors, there are no micro-cracks to be seen on specimens quenched immediately after welding (Flanigan and Kaufman,[35] Flanigan and Saperstein[36]) and, to obtain immunity, there must be an isothermal rest period before quenching, the duration of which, between 700 and 100°C., depends on temperature and shows a definite maximum in the neighbourhood of 470°C. Should it be confirmed, this effect cannot yet be clearly explained, but it may be said that this kind of experiment is very difficult to perform correctly and that it would be necessary to resume it, with a parallel study of the γ–α transformation and of the amount of hydrogen left in the metal after the isothermal rest period: indeed, it should not be forgotten that the diffusion rate of hydrogen undergoes a marked variation during the γ–α change and is suddenly increased by this transformation.

Conclusions

The present progress of research on the behaviour and effects of hydrogen in iron makes it possible to consider as elucidated the main lines of the phenomena involved.

Nevertheless, many points still have to be clarified, more particularly the form or forms of hydrogen in iron and the localization of these various forms (protonic, atomic, and molecular) in defects which, on various scales, exist in the structure. The localization

of these various forms certainly depends on the time elapsed since the introduction of hydrogen in the metal.

Since Professor Houdremont, to whom we are paying tribute today, emphasized the part played by hydrogen in the formation of flakes, the investigations carried out have mainly dealt with forged or rolled steels. The ground has not been explored to the same extent as regards the hydrogen introduced during the welding operation, and it is greatly to be hoped that, with the development of high yield strength weldable steels, used more particularly by the nuclear and steam industries in steadily increasing thicknesses, laboratories will turn their efforts towards the problem of hydrogen in welding.

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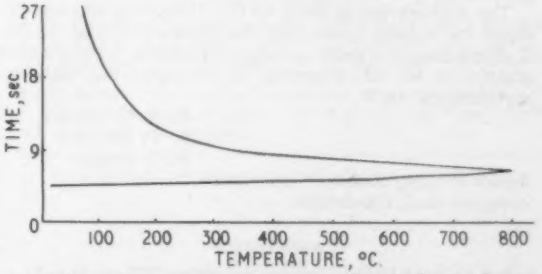
LETTERS TO THE EDITOR

Effect of Rapid Heating and Cooling on the Microstructure of a Normalized 0·2% C Steel

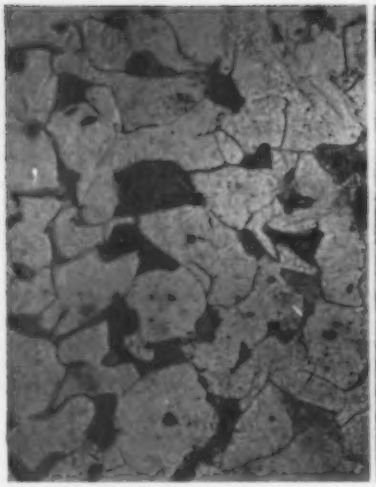
It has been shown by Calvo[1] that when normalized 0·2% C steel is rapidly heated and cooled, martensite pools may be formed within the pearlite grains. To investigate this phenomenon further, disc-shaped specimens were subjected to intense localized heating with an argon-arc spot welding apparatus using a technique developed by Calvo.[2] Regions near the melted pool attained a recorded peak temperature of 800°C. in 2½ sec, and when the arc was cut off, subsequent cooling was very rapid. Cooling from peak temperature to 200°C. took place at a mean rate of about 120°/sec. Figure *A* shows a graph of temperature against time for the region examined. The temperature was sufficiently high for the pearlite to be transformed to austenite. The regions of austenite then tended to grow at the expense of the surrounding ferrite.

On quenching, the centres of the former pearlite colonies transformed to martensite of approximately eutectoid composition. However, at the periphery of the colonies, where carbon diffusion into the ferrite had occurred, the carbon content was lower and a bainitic structure was formed. Figure *B* shows a region of the specimen corresponding to the temperature cycle illustrated in Fig. *A*. The surface illustrated was polished and etched before heating, and the structure thus revealed can still be seen after the thermal cycle. Figure *C* shows the same area after repolishing and etching to show the new structure. Light-etching regions are clearly defined within the former pearlite colonies, whilst at the periphery of these colonies, a bainite structure has been produced. Grain growth has occurred in the ferrite.

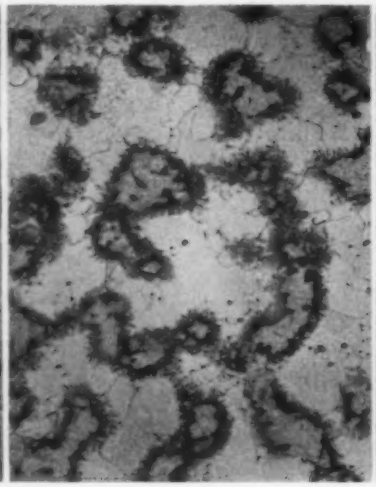
Microhardness measurements carried out on the pools over a range of loads show that the hardness was well over 900 D.P.N. The results are tabulated below. Some of the



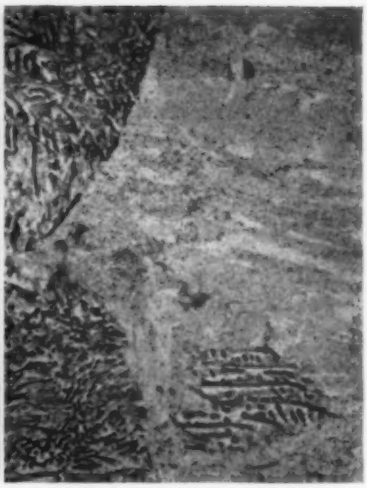
A—Relationship between temperature and time, showing heating and cooling cycle experienced by region examined



B—Polished and etched surface of normalized 0·2% C steel, after thermal treatment shown in Fig. A, showing original etched structure, and superimposed detail due to heating and cooling ×500



C—Same field as Fig. B, after lightly repolishing and re-etching to reveal the underlying microstructure ×500 (Reduced ×¾ linear in reproduction)



D—Electron micrograph, showing boundary between martensite pool and bainite surrounding it. An 'island' of partially dissolved pearlite within the martensite is also visible (direct carbon replica) ×4,000

scatter may be attributed to the small size of the pools and the difficulty of estimating their depth below the free surface.

Load, g	*Micro-Hardness D.P.N.*	*No. of Readings*
9·5	984	17
18·5	897	20
27	954	8

Examination with the electron microscope revealed a mottled substructure within the pools, and with prolonged etching the outline of martensite needles began to appear. Figure *D* shows a typical structure with a boundary region between martensite and bainite, and there is also apparently an 'island' containing partially dissolved carbide within the martensitic pool.

The hardness of eutectoid martensite[3] is ≏ 900 Hv; very near the microhardness values observed. Although one cannot strictly compare microhardness with macrohardness, there seems little doubt that the pools consist of martensite, formed by quenching austenite of near eutectoid composition. It is not known at present whether the structure of the martensite differs from that obtained when eutectoid steel is quenched after prolonged solution treatment. The mottled structure of the pools tends to suggest lack of homogeneity, perhaps because of incomplete solution of carbides. It is proposed to use thin film techniques with transmission electron microscopy to investigate the structure of the pools further.

The authors are grateful to Dr. J. Nutting and Dr. W. Biggs for helpful comments and discussion, and to Dr. R. Weck for his interest and encouragement. They are also grateful to Mr. G. Regelous for his assistance with the experimental work.

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Hot Cracking in Welds

I have read with much interest the article by W. K. B. Marshall on hot cracking in mild and alloy steel welds.[1] A comprehensive literature survey[2] on cracking in Cr-Ni austenitic steels, by Borland and Younger, has been published recently in the *Journal*. It was concluded that the main effect of ferrite in preventing cracking was due to its capacity for dissolving larger quantities of harmful elements like phosphorus, silicon, and niobium than austenite and to its action in creating an increased grain boundary area which thins out the liquid films and also lessens the tendency for segregation.

Since the present theories of hot cracking do not appear to account completely for all the observed facts I have attempted to develop a "Generalized theory of supersolidus cracking".[3] One important aspect of this theory is that for cracking to occur *it is not a sufficient condition that a wide freezing range exists; the liquid should also be present over a relatively wide temperature interval in a distribution that will allow high stresses to be built up between grains.* Here the dihedral angle is an important factor, particularly in ternary and more complex alloys. This theory has now been applied to the problems of cracking in mild and low-alloy steels,[7] and I have pointed out that austenitic and ferritic structure play a large part in promoting and preventing cracking respectively; in fact, the explanations given for the effect of various elements are very similar to those offered by Marshall.

A possible criticism of Marshall's work is that he based his initial premise, that ferrite is beneficial, on evidence in a paper[4] that dealt with cracking not only in the weld but also in the heat-affected zone and gave an empirical formula based on 'mixed' results. The formula, summarizing the conclusions, can hardly be equally applicable to both types of cracking, for the basic mechanisms encouraging liquid to form at grain boundaries are very different in the two cases. Furthermore, the suggested beneficial effects of chromium, molybdenum, and vanadium were attributed to their carbide forming tendencies and thus in this context cannot directly support Marshall's conception of their role as ferrite formers. That these criticisms can be aimed, does, to some extent, distract attention from the good points made by Marshall,

particularly in his reference to the work of other authors. Nevertheless, I would wish to support him in many of his arguments, and would add the following brief comments taken from the article on mild and low-alloy steels. (Reference to the effect of the dihedral angle is deliberately omitted as this aspect is discussed more fully in my published note[3] and in my forthcoming article).

Effect of elements in ferritic* steels

The most potent elements on a weight basis, causing cracking, are sulphur and boron. In the absence of manganese these elements are equally potent, but when manganese is present, as is usual, boron is somewhat more harmful. Less potent elements are phosphorus and arsenic. Silicon is not harmful by itself. Oxygen can be *beneficial*. The benefits of oxygen are reduced by aluminium, which is a strong deoxidizer. Silicon acts in a similar but very much less effective manner.

The relative potency (R.P.) of *small amounts* of elements forming solid solutions can be judged by their effect in increasing the freezing range, and numerical values can be obtained from the following relationship:

$$\text{R.P.} \sim M_L \left(\frac{1-K}{K}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where M_L = slope of liquidus (°C./wt. %)
K = partition coefficient.

An idea of the real effect of an element can be estimated by multiplying the R.P. factor by the concentration of solute. This arithmetical process cannot be extended too far, however, for a maximum cracking susceptibility is obtained before the solid solubility is reached. There are good reasons for this. Table A indicates the relative and maximum potency (column 4) of elements in ferritic steels. It cannot be used of course to give an indication of the effect of an element when certain others are present; *e.g.*, sulphur in the presence of manganese. Also to be effective and to be judged the element must be capable of reaching a certain 'minimum qualifying standard' of maximum potency. For example, carbon, although having a large R.P. factor (322), cannot assume the importance of phosphorus, which has a lower R.P. factor (121) because, at worst, the freezing range can reach only about 32°C. At the moment, unfortunately, it is not possible to extend these thoughts very far because of lack of data. Similar arguments can be extended to aluminium alloys; Fig. 1, for instance, taken from other of my unpublished work[6] shows the potency of small amounts of elements in aluminium. Here it is to be noted that, despite the high relative potency of iron, it is not very harmful because of its small maximum potency. Manganese, which has a low R.P. factor and maximum potency, and thus should not be harmful, is in fact slightly harmful, but only because of its effect on sub-solidus cracking.[6]

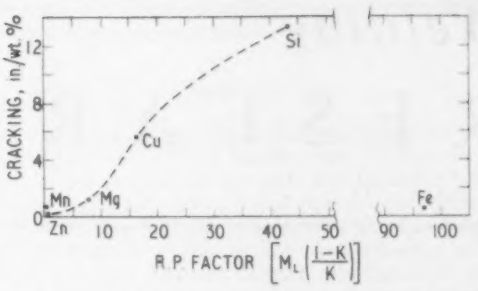
* Initially solidifies mainly as ferrite.

Table A

Cracking potency† of elements in iron-binary alloys

Element	*R.P. Factor* $M_L\left(\frac{1-K}{K}\right)$	$M_L\left(\frac{1-K}{K}\right)Co$ $Co=0{\cdot}01\%$	$Co=\frac{Max.}{Solid\ Solubility}$
C	322	3·22	32·2
Cu	3·61	0·0361	22·5
Mn	26·2	0·262	26·2
Co	0·30	0·003	5·22
Ni	2·93	0·0293	18·2
Be	5·41	0·054	40·0
Si	1·75	0·0175	32·4
P	121·0	1·21	338·0
Ti	13·8	0·138	97·0
As	40·2	0·402	442·0
Sn	16·8	0·168	270·0
Sb	(5·04)	(0·0504)	(176)
Al	1·52	0·0152	55·3
Zr	15·2	0·152	109·0
Nb	28·8	0·288	130·0
Ta	13·0	0·130	91·2
B	917·0	9·17	137·0
S	925·0	9·25	166·0

† Cracking is not, of course, proportional to these factors, but nevertheless they serve as a rough guide.



1—Effect on cracking in aluminium alloys of factor $M_L\left(\frac{1-K}{K}\right)$ *of various elements*[5]. *(Cracking data from ref. 6.)*

Effect of elements in austenitic‡ steels

Boron and sulphur are extremely potent in austenitic structures. Sulphur (in the absence of manganese) is probably about 3·6 times more harmful than it is in ferritic structures. Phosphorus will assume more importance as will also arsenic, tin and antimony, because of their reduced solubility in austenite.

Carbon, manganese and nickel, are crack promoters and act mainly in the manner described by Marshall; *i.e., they increase the quantity of austenite initially solidifying from the melt*. The effect of manganese is reduced to some extent by the presence of sulphur and oxygen. As the amount of austenite increases, higher Mn/S ratios are required to offset cracking because of the *reduced solubility of sulphur* and *increased solubility of manganese* in austenite.

Silicon is only slightly harmful in high-alloy steels, where it is not present in sufficient quantities to form ferrite.

Not until data on the partition coefficients of various elements in austenite and the appropriate liquidus (or solidus) is determined can the effect of elements in austenitic structures be rationalized.

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‡ Initially solidifies mainly as austenite.

(Refer also to foot of p. 587)

Welding
RESEARCH

B.W.R.A. REPORT

High-Tensile Preloaded Bolted Joints

FOR DEVELOPMENT OF FULL PLASTIC MOMENTS

By L. G. Johnson, M.A., A.M.I.STRUCT.E., *J. C. Cannon*, M.A., *and L. A. Spooner*, A.M.I.STRUCT.E.

The report gives the results of tests carried out to determine whether high-tensile pre-loaded bolts could be used to develop the full plastic moment of the connected members in certain types of rigid joint found in mild steel structures. Six tests were performed, with different joint details, four having bolts in equivalent shear and two having bolts in combined tension and shear.

Introduction

In certain types of rigid joint found in mild steel structures, rivets and black bolts are usually considered to act in shear, bearing, or tension or a combination of these stress conditions. A preloaded bolt, however, is known to set up large frictional forces between the surfaces joined, and it is assumed that all except tensile loads are transmitted by this friction. The high initial tensile stress is induced in the bolt when the nut is tightened down on to a hardened steel washer usually by means of a torque control spanner or a pneumatic impact wrench.

The relation between the applied torque and the tension in the bolt can be expressed in the form:

$$T = C \times d \times W_p$$

where T = applied torque
C = torque coefficient (non-dimensional)
d = nominal bolt diameter
W_p = bolt preload

An American Specification[1] quotes a torque coefficient value of 0·2 for a non-lubricated bolt and nut. A German preliminary Specification[2] is based on a coefficient of 0·163, but the required torque is then increased by 10%, giving a working coefficient value of 0·179. Investigations carried out by Munse[3] show values of torque coefficient varying between 0·292 and 0·181 with an average of 0·221.

The slipping load of a bolt or its 'equivalent shear' value is given by:

$$S = \mu \times f_p$$

where S = slip load at first major slip
μ = friction factor
f_p = compressive force between plies.

The friction factor for various lap joints was found by Nachtman[4] to lie between 0·24 and 0·45 with an average of 0·34. Similar tests carried out in Britain[5] showed that out of 108 experiments only six gave results lower than 0·4, with 90% giving values between 0·4 and 0·6. The German preliminary specification quotes figures of 0·45 and 0·6 for mild steel and high-tensile steel respectively, which are used in conjunction with a factor of safety against slip of 1·25 for normal structures and 1·6 for bridges and crane structures. Theses figures are, however, based on the condition that the contact surfaces are flame cleaned or sand blasted. The American specification gives no indication of a value for the friction factor. It allows for the direct substitution of one high-tensile bolt for a rivet of the

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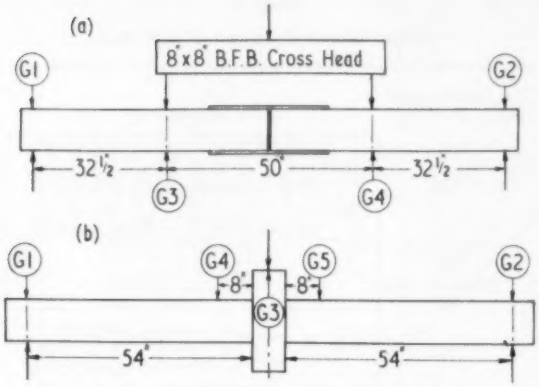
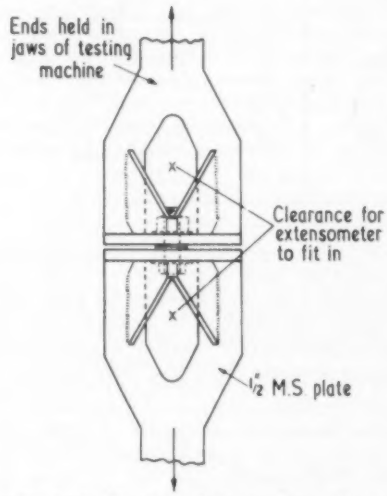
Mr. Cannon and Mr. Spooner were postgraduate students in the Engineering Dept. of Cambridge University when this work was carried out.



1—*Testing arrangements:* (a) *Specimens 1 and 2;* (b) *specimens 3–6*



2—*Rig for holding bolts during load/extension tests*

same nominal diameter. Adopting this procedure for current BS. values, a ¾ in. dia. bolt pretensioned to 11·4 tons with an 'equivalent shear' value of a ¾ in. dia. shop rivet would give a friction factor of 0·273.

From an examination of previous experimental work it was to be expected that there would be considerable variations in the values of the torque coefficient and friction factor. For this reason it was decided that during the tests the torque value should remain as nearly constant as possible so that the variation in torque coefficient could be observed, the friction factor being evaluated from the load at first major slip.

When preloaded bolts are subjected to an applied external force it can be shown theoretically[6] that the two tensile loads are not additive. This feature of the preloaded bolt is clearly demonstrated by the fact that the German preliminary specification allows the applied external tension to equal 80% of the initial bolt preload.

In the investigation, six tests were carried out, four with the bolts in 'equivalent shear', two of these being beam splices subjected to pure bending, and two being beam-to-stanchion connections. Two further tests were made with beam-to-stanchion connections having the bolts in combined tension and shear.

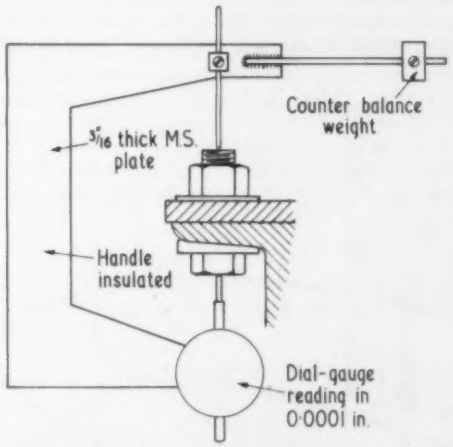
Specimens

The test specimens were fabricated from mild steel to BS.15: 1948. All the beams were 10 in.×4½ in. R.S.J.'s, the stanchions for tests 3–6 inclusive being 8 in.×8 in.×45 lb broad flange beams. The arrangement of loading and the positions of the dial gauges for each test are shown in Fig. 1, all testing being carried out in a 500 ton Amsler machine. The area around each joint was coated with ordinary plumber's resin so that the formation of yield zones and the development of plastic hinges could be observed.

Bolts

The bolts used throughout the tests were ¾ in. dia.× 2½ in. long supplied to A.S.T.M. Standard A 325–55T being a 0·3% C, 0·3% Mn, quenched and tempered steel with a specified minimum proof stress of 37·9 tons/sq.in. and a minimum ultimate stress of 53·5 tons/sq.in. They were used in the as-received condition complete with hardened steel washers under both nut and head.

Load/extension tests were carried out on seven bolts using a grip length of 1 9/16 in. This length was decided upon because it was the standard for all the bolts in specimens 1, 2, 3 and 4. The test rig, shown in Fig. 2, was used to hold the bolts during loading, and the extensions were measured by a dial gauge extensometer (Fig. 3), which measured directly the change in



3—*Dial gauge extensometer*

bolt length to 0·0001 in. The bolt was first centre-punched at each end, the extensometer was then balanced on its fixed pointer and left in position throughout the test.

The variation in the extensions of the seven bolts tested was of the order of 20% from the mean at a load of 13 tons. This variation decreased at lower loads but increased to 30% at a load of 16 tons. The graph shown in Fig. 4 was obtained by plotting the mean values for all the bolts. This curve was used to estimate the preload in each bolt in the test specimens.

Joint assembly

A simple torque spanner was used to tighten the bolts, the torque being read from a gauge integral with the head of the spanner. The spanner was calibrated for the range 220–360 ft-lb and was adjusted to give a true reading at 320 ft-lb. The calibration curve is shown in Fig. 5.

The American specification gives a working torque value of 320 ft-lb for $\frac{3}{4}$ in. dia. bolts. The specification states, however, that this value is an experimental approximation applicable to non-lubricated threads, and that if torque rather than tension is to be measured the torque/tension ratio shall be determined by the actual conditions of the application. For this investigation it was decided to use a torque of 320 ft-lb throughout as being the figure that most commercial users would acept as a working value. For all tests the torque was applied to the nut, the bolt head being gripped to prevent its rotation.

All traces of dirt, grease, rust, and mill scale were removed from the contact surfaces by simple cleaning and wire brushing. The bolts were given an initial torque of less than 320 ft-lb, so as to bed the plates down; they were then slackened off in turn, screwed finger-tight and finally brought up to the full value of 320 ft-lb. Table I gives the initial values of the torque and the sequence of tightening for each test.

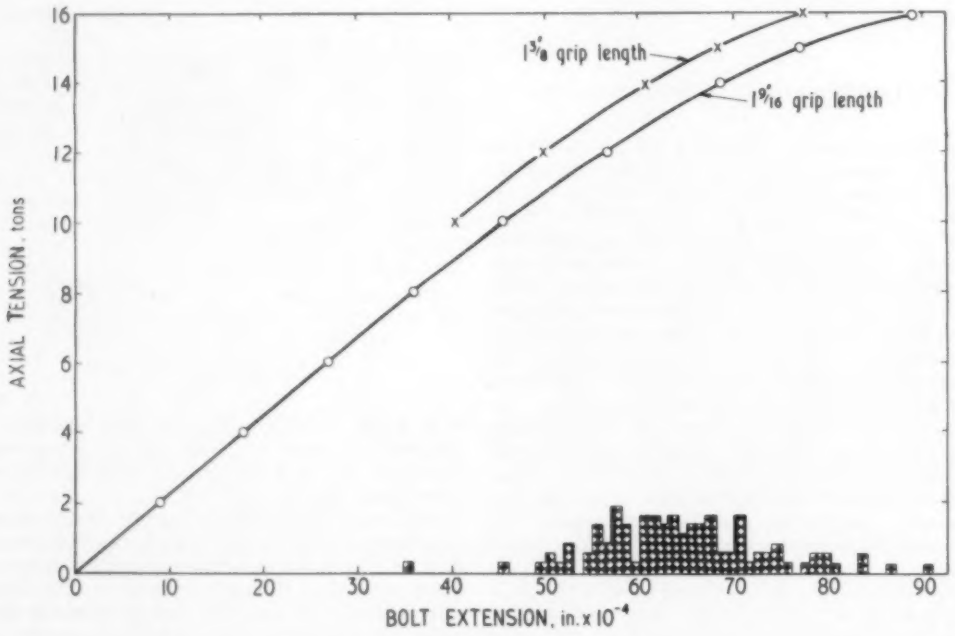
Bolt extensions were determined by measuring the change in length from the finger-tight condition to that at the full working torque. The measured extensions of all the bolts were converted into equivalent loads on the basis of the curves in Fig. 4, and the results are shown in the form of a histogram on this graph. Specimens 4 and 5 did not permit the use of the balanced extensometer, and it was found that reliable measurements could not be taken using a similar hand-held instrument. Bolt extensions therefore were not recorded for these two tests.

In specimen 6 the bolt grip lengths were only $1\frac{3}{8}$ in. A load-extension curve was deduced for this grip from the calibration curve in Fig. 4, assuming a linear relationship between the $1\frac{3}{8}$ in. and $1\frac{9}{16}$ in. lengths.

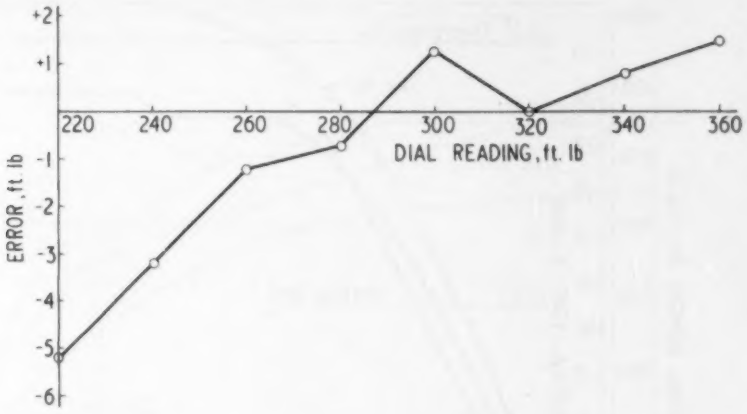
Table I

Torque values and sequence of tightening

Test No.	*Initial torque ft-lb*	*Order of tightening*
1	100	Initial: 11 7 3 1 5 9 | 23 19 15 13 17 21 / 12 8 4 2 6 10 | 24 20 16 14 18 22 Final: 1 2 3 4 5 6 | 7 8 9 10 11 12 / 13 14 15 16 17 18 | 19 20 21 22 23 24
2	top flange 100 bottom flange 240	5 1 3 | 9 7 11 / 6 2 4 | 10 8 12
3	240	Similarly for other three wing plates
4	240	Similarly for other three flanges
5	240	Similarly for other three flanges
6	240	Similarly for other beam



4—*Bolt calibration curves*



5—*Torque spanner calibration curve*

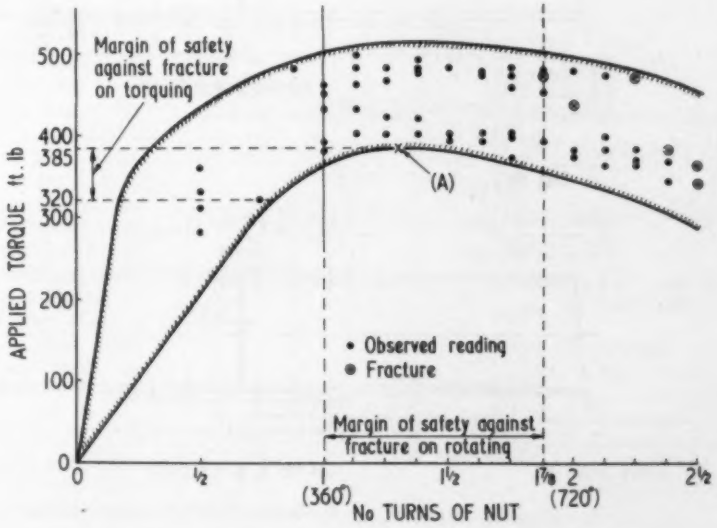
The angular rotations of the nuts on tightening from the finger-tight position to that at the full working torque were also measured. Table II shows the average bolt preloads, torque coefficients, and nut rotations for each test together with the maximum and minimum values. There are considerable variations in the bolt preloads as deduced from the extensometer measurements but the average value is greater than the American specification's minimum tension of 11·4 tons. Unfortunately, little significance can be attached to this result because the determination of the bolt load from the extension is not a very reliable procedure, as was proved by the load/extension tests. The variations in the nut rotations too are considerable for they depend upon the amount of bedding down that takes place, the load/extension properties of the bolt, and the frictional resistance.

Table II

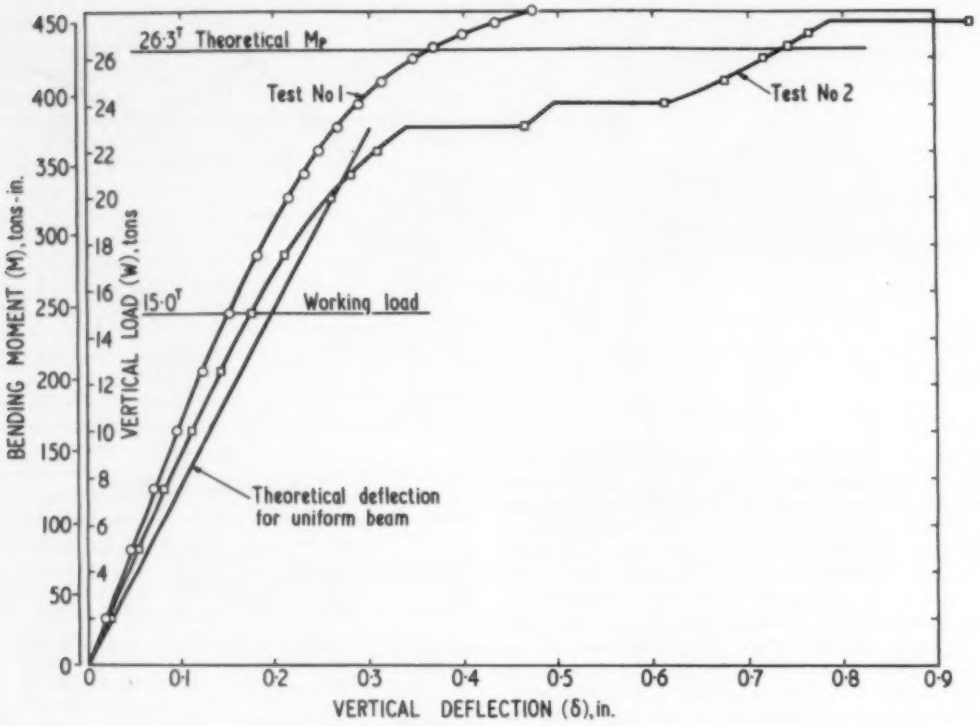
Bolt loading conditions

Test		*No. 1*	*No. 2*	*No. 3*	*No. 6*	*All*
Bolt preload, tons	Max.	15·3	15·2	16·1	15·9	16·1
	Min.	11·0	7·9	11·2	12·1	7·9
	Av.	13·1	12·65	13·3	14·6	13·3
Torque coefficient, *C*	Max.	0·208	0·29	0·204	0·189	0·29
	Min.	0·149	0·15	0·142	0·144	0·142
	Av.	0·175	0·181	0·172	0·156	0·172
Nut rotation, degrees	Max.	230	225	360	—	360
	Min.	100	85	75	—	75
	Av.	151	153	170	—	158

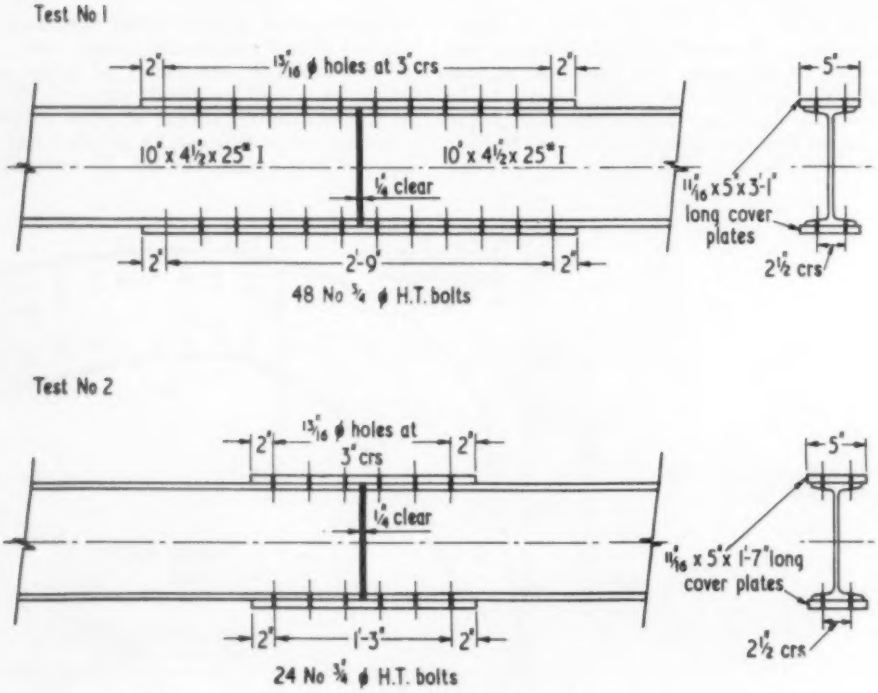
Experiments were carried out on six bolts to determine the relationship between the applied torque and the angular rotation of the nut. The results are plotted in Fig. 6. The first point to note is that from 2 to 2½ complete turns of the nut were required to cause failure of a bolt. Further inspection of Fig. 6 leads to the conclusion that it should be possible to work to a higher bolt preload when tightening to a given rotation than if a particular torque value were adopted. For example, the factor of safety against bolt failure for a working torque value of 320 ft-lb would be 1·2, because the torque at point *A* (Fig. 6) is the maximum value that can be specified and still ensure that the bolt remains intact. If, instead, the nut is



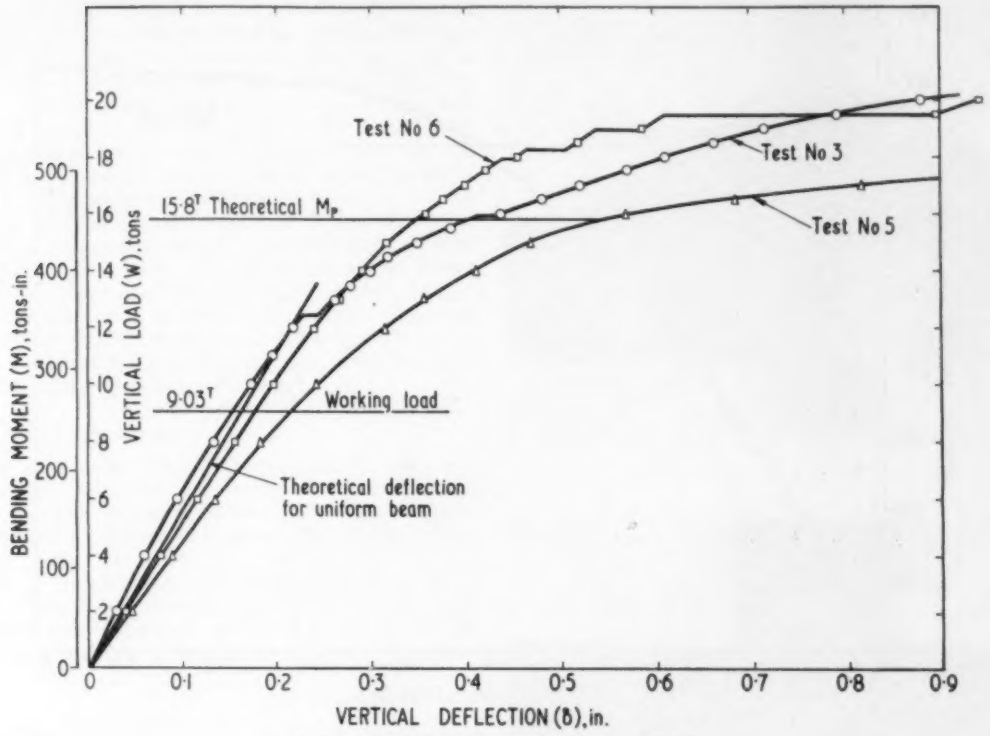
6—*Relationship between applied torque and angular rotation of nut*



7—Moment/deflection curves for tests 1 and 2



8—Details of joints for tests 1 and 2



9—Moment/deflection curves for tests 3, 5 and 6

given a rotation of one complete turn the minimum applied torque would be 365 ft-lb and the maximum 500 ft-lb, the factor of safety, however, being increased to 1·87.

Results

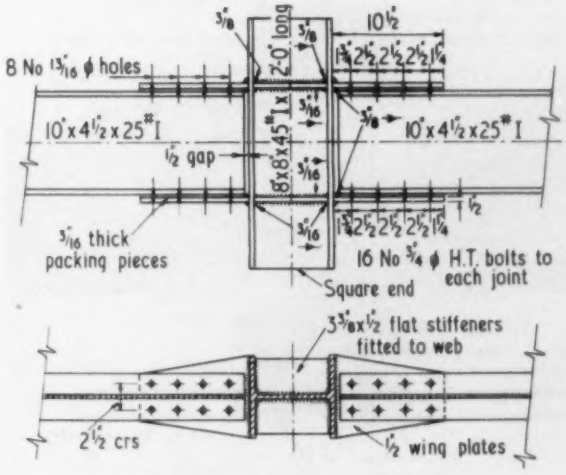
Test 1 (Figs. 7 and 8)

This joint was designed as a riveted splice, to resist bending moment only. The reduced plastic moment of the section, allowing for the reduction in area due to the holes, and assuming a yield stress of 15·25 tons/sq.in., was 310 tons in. High-tensile bolts were substituted for rivets on the basis of one for one.

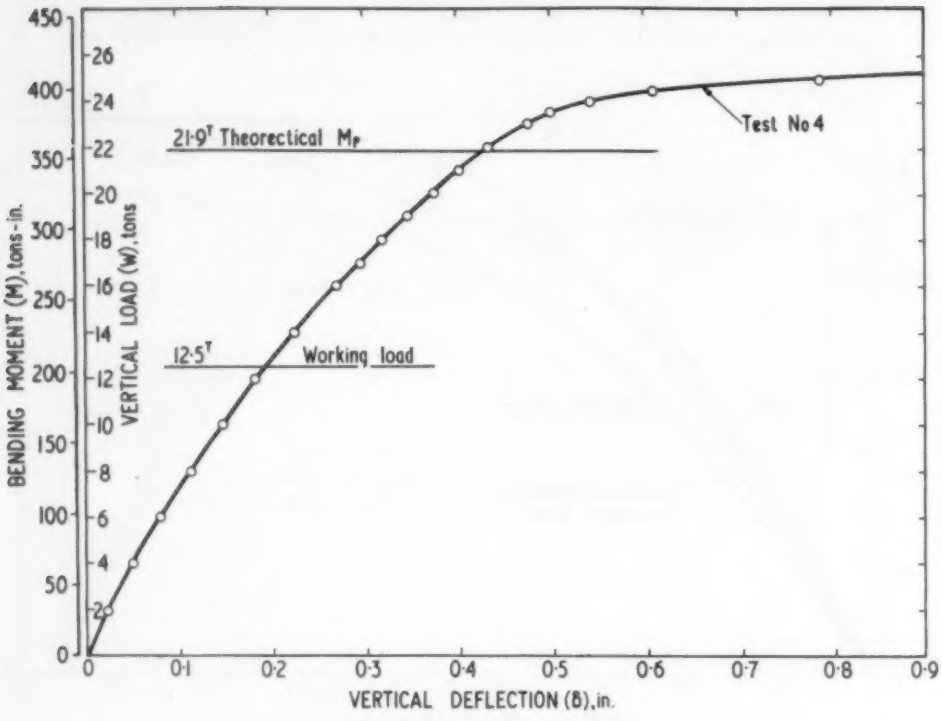
There was no sign of slip at any stage during the test. The specimen was subjected to a maximum bending moment of 455 tons in., at which point yielding had begun in the flanges of the joists at the ends of the coverplates but the actual, as opposed to the theoretical, full plastic moment had not quite been reached. It is obvious from Fig. 7 that the flange plates must have had a stiffening effect on the section as a whole. In fact, if the theoretical deflection is calculated, allowing for the moment of inertia of these plates but with no reduction for the bolt holes, good agreement is obtained with the elastic portion of the experimental curve.

Test 2 (Figs. 7 and 8)

This connection was similar in design to that used in the previous test, but the number of bolts was reduced by 50%. At a moment of 372 tons in. the first slip occurred and was accompanied by a very loud report. Two further slips took place at moments of 390 and 445 tons in., after which the bolts appeared to come into direct bearing. Plastic hinges formed in the beams at the ends of the cover plates at a moment of 455 tons in. The 'equivalent shear' per bolt at the first slip was 6·2 tons, the average bolt preload being 12·65 tons, giving a friction factor of 0·49. As in


8 No 13/16 φ holes
10" x 4½ x 25# I
½ gap
18"x8"x45# I
5/16 thick packing pieces
16 No ¾ φ H.T. bolts to each joint
Square end
3⅜"x½ flat stiffeners fitted to web
2½ crs
½ wing plates

10—Details of joint for test 3

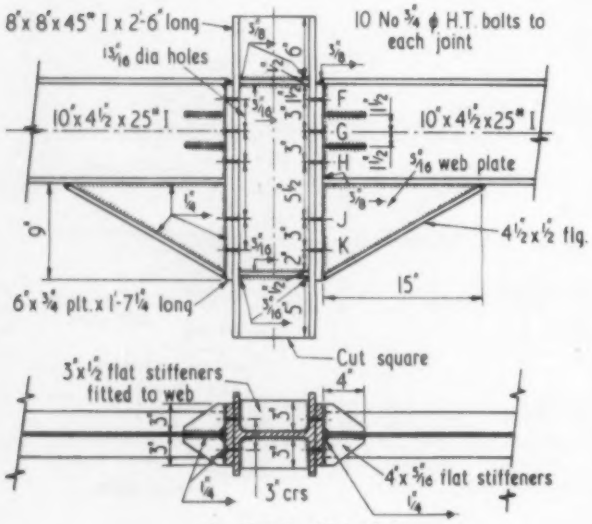


11—*Moment/deflection curve for test 4*

test 1 the cover plates had a noticeable stiffening effect on the parent joist section.

Test 3 (Figs. 3 and 10)

This was an attempt to design a joint that would be capable of transmitting the full plastic moment of the beam (428 tons in.) at the face of the stanchion. A friction factor of 0·45 was used to determine the number of bolts required through the wing plates. Packing plates $\frac{3}{16}$ in. thick were introduced to each flange to give the required bolt grip length of $1\frac{9}{16}$ in. and also to facilitate assembly. In fact, the packing plates had to be tapered because the wing plates had been pulled out of parallel by the contraction due to welding, and the contact surfaces were not by any means seating flush all over.



12—*Details of joint for test 4*

At a moment of 335 tons in. there was a sudden drop in load, and from Fig. 9 it would appear that this was the first major slip. A second slip occurred at 431 tons in. and this was followed by more or less progressive slipping until the bolts came into direct bearing. Unlike previous examples, these slips were not accompanied by any noise and would not have been noticed except for the falling off in load indicated by the recording device on the testing machine.

A plastic hinge formed in one beam beyond the wing plates with a moment at the stanchion face of 635 tons in., the moment at the hinge being 511 tons in. The equivalent shear per bolt at the moment of 335 tons in. was 4·19 tons, the average bolt preload being 13·3 tons, giving a friction factor of 0·315. This rather low value for the friction factor was undoubtedly primarily due to the incomplete contact between the wing plates and the joist flanges. This difficulty was overcome in test 6.

Test 4 (Figs. 11, 12 and 13a)

Figure 11 shows that the joint behaved rigidly during the initial stages of the test and that plastic

hinges developed in the beams immediately beyond the haunches at a moment of about 495 tons in., *i.e.*, 16% greater than the theoretical value based on a yield stress of 15·25 tons/sq.in. The moment at the face of the stanchion was then 686 tons in. Taking the centre of rotation of the bolt group as the bottom row of bolts and also as the bottom flange of the joist, the tensile load in each of the top line of bolts was calculated as 11·0 and 18·6 tons respectively.

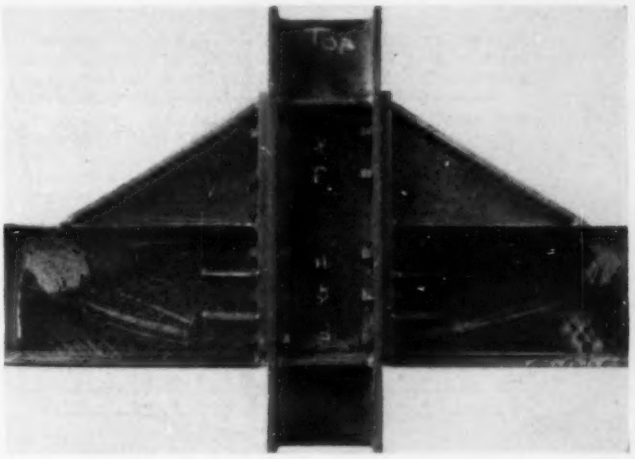
It was noticed that the stanchion flanges deformed in the region between the two uppermost lines of bolts and therefore it would seem that the top web stiffeners would have been more effective if they had been placed in this position, *i.e.*, between bolts *F* and *G*. The web stiffeners to the beam end plate were thought to be rather generous in size and in fact they could perhaps have been dispensed with altogether.

Test 5 (Figs. 9, 13b and 14)

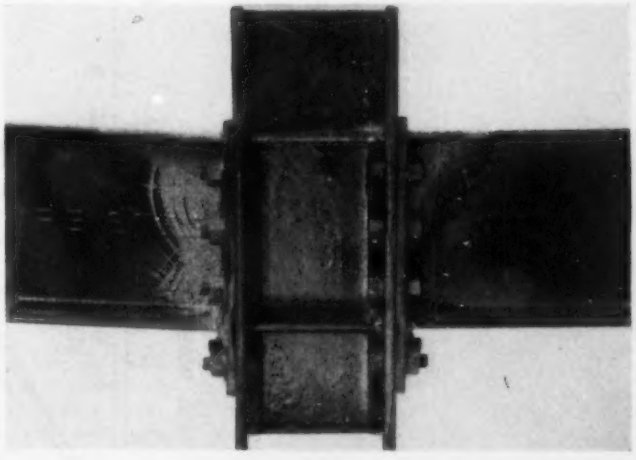
This test was carried out to determine the efficiency of a welded end plate extending above the tension flange but without any additional stiffening. The joint did transmit a moment in excess of the theoretical full plastic value, but at 486 tons in. there was a local failure of one end plate near the tension flange of the beam. Close examination of the fracture revealed that the plate was laminated, so this test should not be taken as a fair representation of this type of connection.

Test 6 (Figs. 9, 13c and 15)

This connection was a modification of that used in test 3 and was designed to overcome the earlier assembly difficulties. The stool cleat bolts were allowed to remain finger-tight while the wing plate bolts were tightened, the $\frac{1}{16}$ in. hole clearance allowing sufficient freedom for the contact surface to seat properly. The first slip occurred at a moment of 484 tons in. and was accompanied by a slight cracking noise together with a fall-off in load. As can be seen from Fig. 9 a series of slips then took place, the last



(a)



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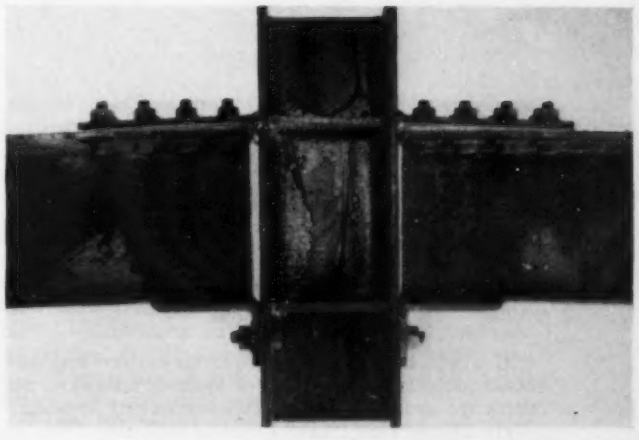
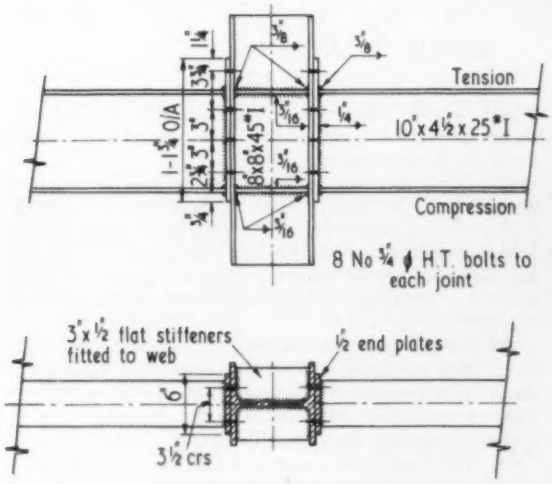
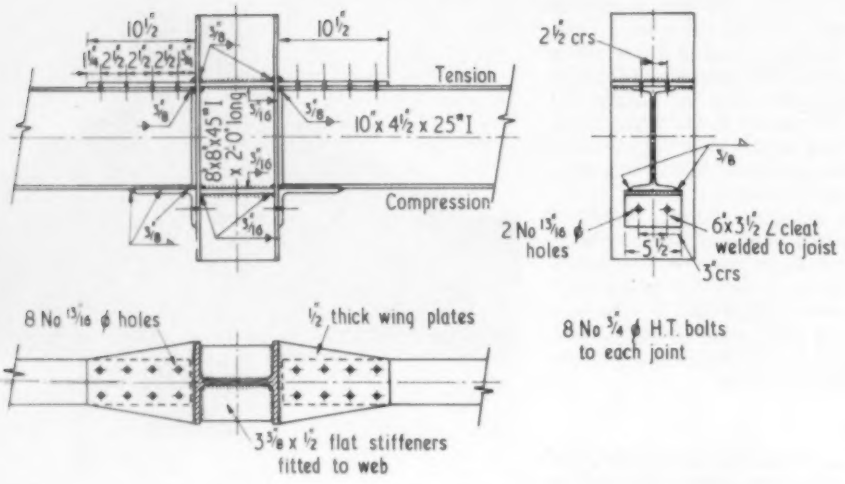


(c)

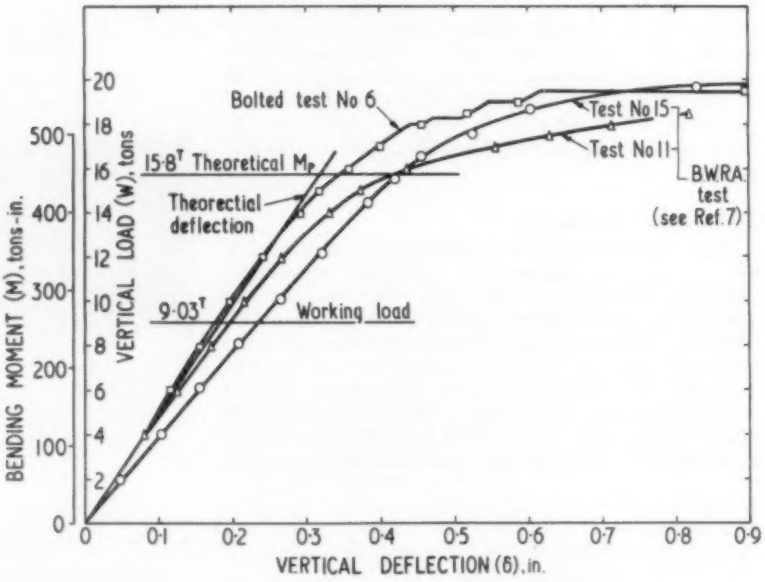
13—*Joints on completion of tests:* (a) *Test 4;* (b) *test (5;* c) *test 6*



14—*Details of joint for test 5*



15—*Details of joint for test 6*



16—*Comparison of moment/deflection curves for bolted and welded connections*

occurring at a moment of 525 tons in. Plastic hinges, running diagonally from the first bolt in the tension wing plate to the toe of the compression angle cleat, formed in both beams at a moment of about 614 tons in. The 'equivalent shear' per bolt at first slip was 6·05 tons. With an average bolt preload of 14·6 tons this gives a friction factor of 0·41.

Conclusions

It would be rather presumptuous to draw any firm conclusions from the results of these six tests alone but there are certain features which are worthy of note.

(1) Flange plates have a certain stiffening effect on the parent joist and it would appear in fact that the section acts as a compound member. This was well brought out by the positions of the plastic hinges, which always developed immediately beyond the flange plates and not across the first row of holes as might have been expected.

(2) The tightening of the bolts to a given minimum torque value is not the most efficient way of guaranteeing the preload. It seems from Fig. 11 that a much better method would be one based on a specific angular rotation of the nut, such as the half-torque/half-turn procedure which has been discussed elsewhere.[6]

(3) To develop the maximum frictional grip between two members with bolts acting in 'equivalent shear' it is necessary to ensure that the design of the joint is such that the contact surfaces are not prevented in any way from bedding closely together.

(4) The loading arrangement for tests 3–6 inclusive was chosen to correspond with that used by Johnson[7] for welded beam-to-stanchion connections. A direct

comparison of the load deflection curves for test 6 and Johnson's specimens 11 and 15 is shown in Fig. 16. Until slip occurred, test 6 exhibited better deflection characteristics than the all-welded connections, although this is due no doubt to the stiffening effects of the wing plates.

Acknowledgments

The work described in this report was carried out at the Engineering Laboratory, Cambridge University, under the general direction of Professor J. F. Baker, Head of the Department of Engineering.

Acknowledgments are due to Messrs. Guest, Keen and Nettlefolds who gave the high-tensile bolts used in the tests.

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B.W.R.A. REPORT

Fatigue Strength of Beams with Stiffeners Welded to the Tension Flange

This report contains details of fatigue tests carried out on beams having web stiffeners welded to the tension flange both transversely and longitudinally. The stiffeners were located at positions of zero shear stress and the tests were carried out in uni-directional bending. A parallel series of tests has been carried out on a pulsating tension cycle on plate specimens with welded attachments, simulating the beam stiffener details, in order to determine whether such specimens give results which can be applied to the design of beam flanges.

By T. R. Gurney, M.A., A.M.I.C.E.

In the past, several investigations have been made on the fatigue strength of plate specimens with welded attachments. It has always been assumed that this type of specimen adequately represented the detail involved in the connection of plate girder web stiffeners to the tension flange. As far as is known, however, no tests have ever been carried out to obtain a comparison between the different details which may variously be included in a beam specimen tested in bending.

Report D7/3/59 of the British Welding Research Association, issued to members in March, 1960.

Mr. Gurney is a Principal Research Officer of the British Welding Research Association. 573

In view of this, it was considered of interest to carry out comparative tests on beams in bending with stiffeners welded to the tension flange both transversely and longitudinally. The longitudinal welds were made possible by first of all welding the stiffener to a plate placed longitudinally and in the vertical plane, but it seems certain that the results obtained would be equally applicable to beams having the subsidiary plate in the horizontal plane—a detail which some engineers prefer.

To confirm whether or not tests carried out under axial load on plate specimens with welded attachments produce results comparable with those obtained in tests on beams in bending, it was decided to carry

Table I

Composition and mechanical properties of beam and plate material

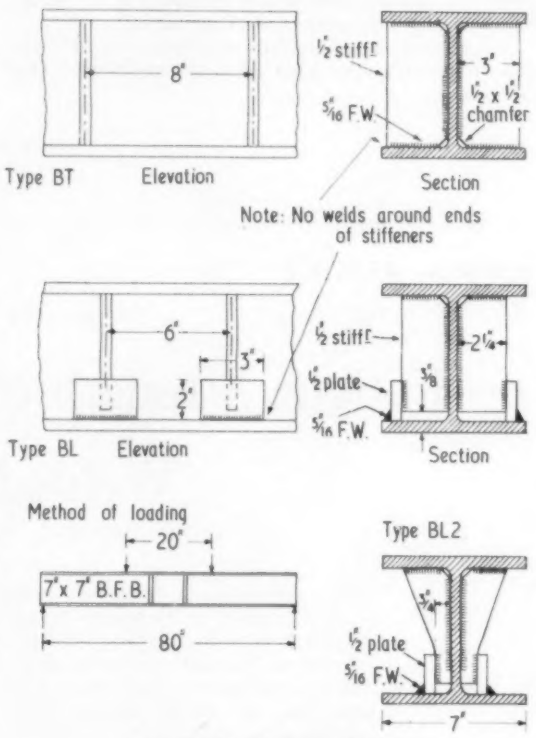
Material		Analysis, % C	Mn	Si	S	P	Yield Stress, tons/sq.in.	U.T.S. tons/sq.in.	Elongation, % on 8 in.	on $4\sqrt{A}$
BS.15 Beam		0·20	0·76	0·037	0·045	0·030	19·0	31·1	25	35
BS.15 Plate	Cast 1	0·185	0·57	0·05	0·030	0·023	18·0	28·5	28	38
	Cast 2	0·125	1·24	0·05	0·045	0·015	19·2	29·8	27·5	37
	Cast 3	0·14	0·76	0·035	0·045	0·030	18·4	28·9	24	34

out a parallel series of tests on plate specimens with identical details to those used in the beam programme. The tests on both the beams and the plate specimens have now been completed, the results obtained being given in this report.

Test Specimens

Beam specimens

All the beam specimens were fabricated from 7 × 7 in. × 34 lb B.F.B., rolled from steel to BS.15. Chemical analysis and mechanical properties of the material are given in Table I, and details of the specimens are shown in Fig. 1. Three types of specimen were tested, series BT having stiffeners welded to the flanges transversely and series BL and BL2 having the stiffeners welded to the tension flange longitudinally. Series BL had the welds near the edges of the flange while in series BL2 the welds were placed nearer the web. The broad flanged beam section was chosen for this work so as to represent the normal parallel flanges of a plate girder without the need for making special welded girders. All the welds connecting the stiffeners to the beams were made in the downhand position using rutile electrodes class E.217. The longitudinal fillet welds connecting the stiffeners to the tension flange in series BL and BL2 were made in two halves, starting at the ends and joining in the middle, to avoid so far as possible the effects of end craters.



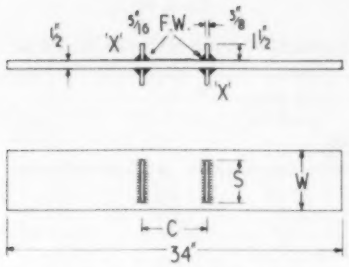
1—Details of beam specimens

Plate specimens with welded-on gusset plates

The mild steel used in these tests complied essentially with BS.15. The plates were ½ in. thick and consisted of basic open hearth semi-killed (balanced) steel without aluminium addition. Steel from three different casts was used, the chemical analysis and mechanical properties of each being shown in Table I. Although the chemical analyses of the plates varied, their mechanical properties were very similar.

The general details of any specimen can be determined from its series identification letters. Thus S indicates that the specimen consisted of a plate with a welded attachment, and when preceded by the numeral 1 that the gusset was welded on one side of the plate only. T indicates that the gussets were welded transversely while N shows that the specimen was tested in the 'as welded' condition (without stress relief). The prefix B indicates that the plate material consisted of flanges taken from the 7 × 7 in. beams with the web machined off. This material had previously formed part of the compression flange of the beam fatigue test specimens. Details of the test series are summarized in Table II.

Full details of the specimens are shown in Figs. 2 and 3. In general they were designed so that the welded details were similar to those existing in the programme of tests on beam stiffeners, although some extra series were tested to determine whether any difference existed between the fatigue strength of specimens with gussets welded on one side of the plate only and of those with gussets welded on both sides. Thus, series 1STN was considered to be directly comparable with series BT—beams with stiffeners welded transversely—and series STN was identical with 1STN except that the specimens had gussets welded opposite each other on both sides of the plate instead of on one side only. The plate for both these test series was rolled from cast 2. The three specimens in series B–1STN, fabricated from beam flanges, were tested to determine whether the difference in material between series 1STN and BT was significant. The



Series	Dimension w	s	c
STN, 1STN	4"	3½"	6"
B–1STN/3	7"	5"	8"
B–1STN/1 and 2	5½"	4½"	8"

Gussets marked *x* omitted from Series 1STN and B–1STN.

2—Details of specimens with gusset plates welded on transversely

specimens in series 1SN 1, 1SN 2 and 1SN 3, were all fabricated from plate rolled from cast 3, and all had gussets welded longitudinally on one side of the plate only. Series 1SN 2 was considered to be comparable with series BL 2, and series 1SN 3 with series BL. The three specimens in series B–1SN were also comparable with series BL and acted in a similar role to series B–1STN, outlined above. Series 1SN 1 was tested so as to complete the investigation of the influence on fatigue strength of the position of a gusset welded to a plate member. For comparison, the results are also given for series SN, which was similar but with gussets welded on both sides of the plate. These latter results were obtained in the course of a previous investigation,[1] the specimens being fabricated from plate rolled from cast 1.

All the plates used were machine gas cut and the specimens were fabricated so that the direction of stressing was parallel to the rolling direction. Welding was carried out in the downhand position using rutile electrodes class E.319. All the fillet welds were made in two halves starting at the ends of the attached plates and joining in the middle to avoid, so far as possible, the effects of end craters. After fabrication the corners of the cross section of the main plates were finished by hand to a radius of approx. $\frac{1}{16}$ in. to minimize the possibility of failure initiation at a gas cut edge.

Method of Testing

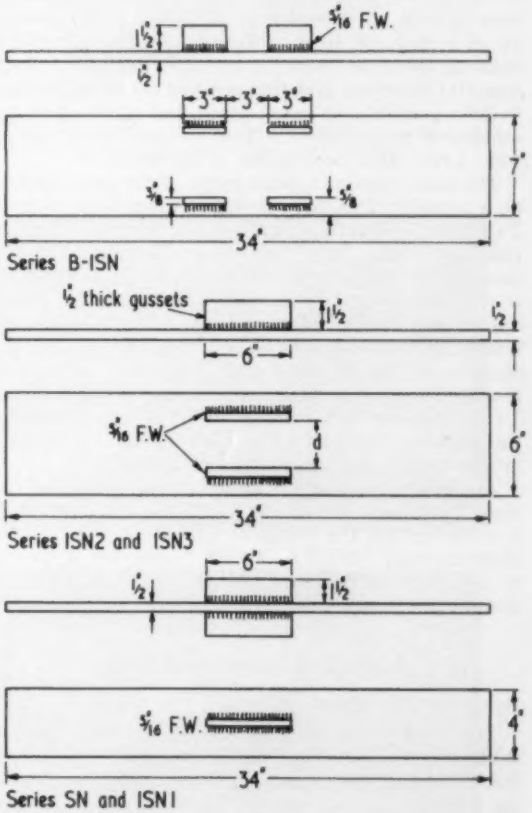
The beam specimens were tested in bending in the 100-ton Illinois walking-beam machine at a speed of approx. 200 c/min. The beam span was 6 ft. 8 in. and the load was applied as two concentrated loads arranged symmetrically 10 in. to each side of the midspan position. In all tests the stress cycle in the lower flange varied from a small tension (approx. 0·5 tons/sq.in.) to a larger tension. Stresses were measured by means of two electric resistance strain gauges placed 1 in. from the edges on the upper side of the tension flange at midspan. The stress recorded in the tables is the mean of the stresses computed from the readings.

Determination of the exact moment of 'failure' was necessarily somewhat arbitrary. The most critical

Table II

Details of test series

Series	*Material*	*Stiffener Arrangement*	*Comparable with Beam Series*
STN	Cast 2	Transverse, both sides	
1STN	Cast 2	Transverse, one side	BT
B–1STN	Beam Flange	Transverse, one side	BT
1SN 1	Cast 3	Single central longitudinal gusset on one side	
1SN 2	Cast 3	Two longitudinal gussets on one side	BL 2
1SN 3	Cast 3	Two longitudinal gussets on one side	BL
B–1SN	Beam Flange	Longitudinal gussets on one side	BL
SN	Cast 1	Single central longitudinal gusset on each side	



Notes:
Series 1SN2, d = 2½".
Series 1SN3, d = 4½".
Gusset omitted on one side for series 1SN1.

3—Details of specimens with gusset plates welded on longitudinally

Table III

Summary of results for Series BT
(Beam with stiffeners welded transversely)

Specimen	*Stress Range tons/sq.in.*	*Cycles to Failure × 10⁶*	*Remarks*
BT/1	14·1	0·264	Failure initiated at one or more points along the toe of the fillet weld
2	12·3	0·352	
3	10·5	0·254	
4	10·2	0·293	
5	10·1	0·687	
6	8·5	1·105	
7	8·2	0·509	
8	7·4	1·600	
9	7·1	3·370	Unbroken
10	6·5	2·121	

Table IV

Summary of results for Series BL and BL2

Specimen	*Stress Range tons/sq.in.*	*Cycles to Failure × 10⁶*	*Remarks*
(a) Series BL			
Stiffeners welded longitudinally, near edge of flange			
BL/1	12·8	0·145	
2	10·9	0·292	
3	7·8	0·945	Crack first seen after $0·932 \times 10^6$ cycles
4	6·5	1·830	
5	5·7	2·691	Unbroken
6	5·3	3·117	
(b) Series BL2			
Stiffeners welded longitudinally further from edge of flange			
BL2/1	12·0	0·229	
2	8·9	0·748	
3	7·4	1·254	
4	6·5	1·554	
5	6·0	1·979	Crack first seen after $1·602 \times 10^6$ cycles
6	5·5	2·572	Crack first seen after $2·181 \times 10^6$ cycles

method appeared to be by means of the strain gauges, a fall in range of approx. 10 μin./in. invariably indicating the existence of a small crack. In many cases, however, the crack was not visible at this stage, and the specimens were therefore kept under test until the machine was switched off by a microswitch placed under the beam at midspan. This was set to operate when the beam deflection increased from its initial state by 0·01 in., at which stage the crack was usually about 2 in. long. In most cases the difference in life between the time when the reduction in stress range was first recorded and the moment when the microswitch operated was insignificant, but cases where the number of cycles between these two events was somewhat larger have been noted in the tables.

The plate specimens were tested under axial loading on a pulsating tension cycle with a lower limit of zero. Two testing machines were used, a Schenck machine running at 2000 c/min, and a Losenhausen hydraulic machine running at 200–400 c/min. The machine used to test any particular specimen is shown in the tables, but no significant difference was found between the results obtained on the two machines. In general, the criterion of failure was taken as the final rupture of the specimen, but those specimens which survived 2×10^6 cycles without apparent cracking were tested statically to failure, and those found to contain fatigue cracks were considered to have failed.

The testing procedure, both for the beam and the plate specimens was based on the establishment of S/N curves for the range of endurance values from approximately 1×10^5 to 2×10^6 cycles, but it should be noted that few attempts were made to produce unbroken specimens after 2×10^6 cycles.

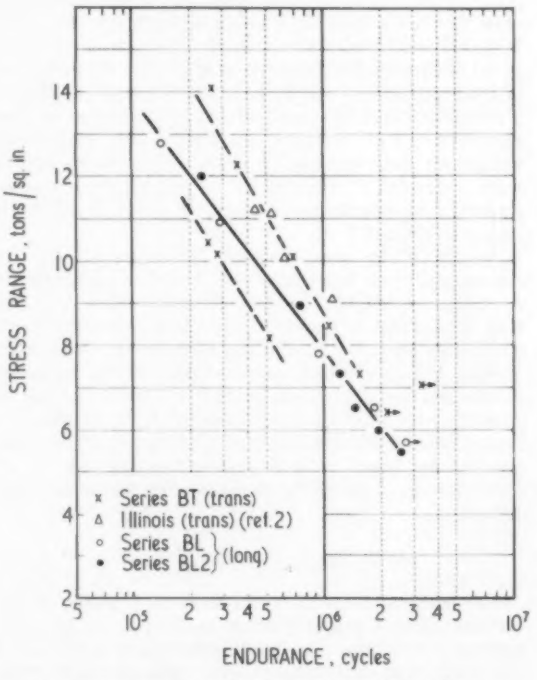
Results and Discussion of Tests

Tests on beam specimens

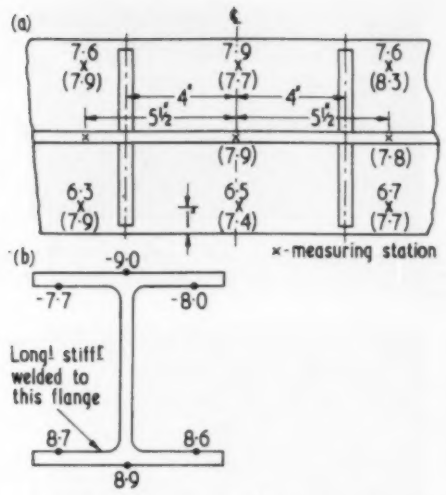
Tests were carried out on beams with three types of stiffener detail: (*a*) With the welding transverse to the direction of stressing—series BT; and (*b*) and (*c*) with the welding parallel to the direction of stressing—series BL and BL2. The test results are given in Tables III and IV, and are shown in the form of S/N curves in Fig. 4.

It was decided to test two series with longitudinal welds so as to determine whether the distance of the weld from the edge of the flange was a significant variable in determining fatigue strength. This possibility had been suggested by some preliminary exploratory tests, which are now known to have been invalid, since the results for the two test series were virtually identical.

Typical stress distributions in the beams in the region of the stiffeners are shown in Fig. 5; with



4—Fatigue test results for beams with welded stiffeners



(*a*) Tension flange, beam type BT (figures in parentheses refer to under side):
(*b*) Centre section, beam type BL.

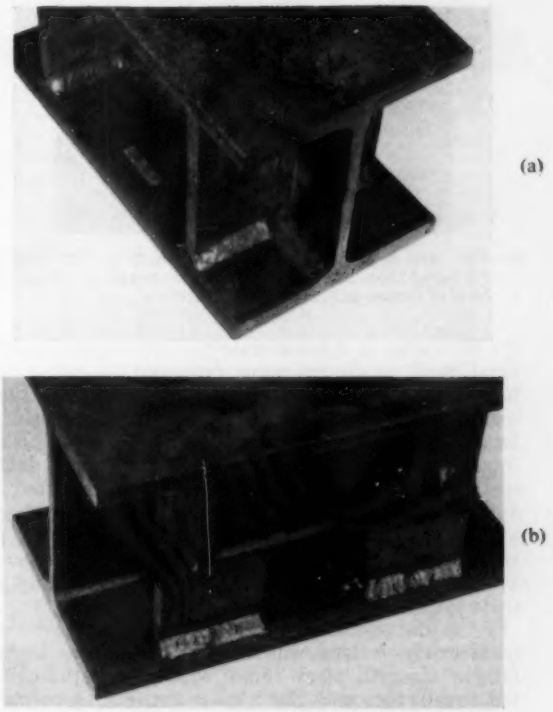
5—Typical stress distributions (tons/sq.in.) near beam stiffeners

stiffeners welded longitudinally, the stress distribution in the tension flange midway between them approximated to a state of axial tension. This was presumably due to the excessive stiffening effect of the closely spaced longitudinal plates, but even though a normal girder would have a stress gradient through the flange thickness it is not considered that this effect in any way invalidates the results obtained.

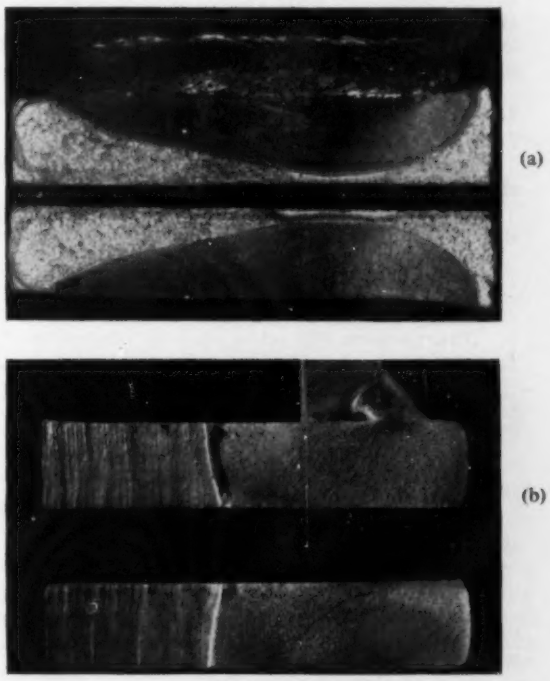
In all cases the mode of failure was as expected, with initiation occurring at various points along the toe of the weld in the case of series BT, and at the end of a weld in series BL and BL2. Typical failures are illustrated in Fig. 6, and typical fracture surfaces are shown in Fig. 7.

Although comparatively few tests have been carried out, very little scatter was experienced in the results for series BL and BL2, and, as can be seen from Fig. 4, the fatigue strength at 2×10^6 cycles was approx. $5\frac{1}{2}$–6 tons/sq.in. for both groups. However, it must be pointed out that no evidence exists that this figure represents the 'endurance limit'. There is a strong possibility that if tests had been carried out with larger endurances lower stresses would have been obtained. This question will be considered more fully later.

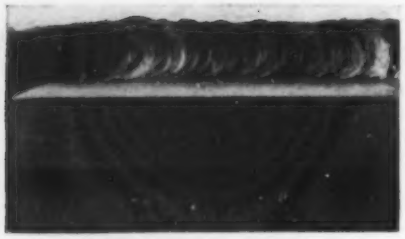
For series BT there was a considerable amount of scatter of the test results, and on subsequent examination it was possible to identify the upper and lower limits of the scatter band with two distinct types of weld. The welds on specimens BT/3, 4, 6 and 10 were much 'rougher' than those on the specimens associated with the upper limit of strength, and careful examination also revealed a very slight amount of undercut, which can be seen in the macro-section from specimen BT/3 shown in Fig. 11*a*. The difference between the two welds is seen in Figs. 8 and 9. It should, however, be noted that both welds would be considered of good commercial quality. From the tests carried out it appears that the upper limit of strength at



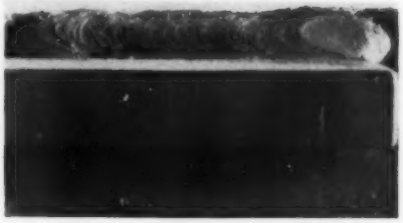
6—Typical fractures of beams: (a) *With stiffeners welded transversely;* (b) *with stiffeners welded longitudinally*



7—Typical fracture surfaces in flanged beams: (a) *With stiffeners welded transversely;* (b) *with stiffeners welded longitudinally*



8—Plan view of fillet weld from specimen BT/3. This weld is typical of those associated with the lower side of the scatter band of fatigue test results



9—Plan view of fillet weld from specimen BT/1. This weld is typical of those associated with the upper side of the scatter band

2×10^6 cycles is approximately 7 tons/sq.in. Insufficient 'bad' specimens were produced to define the lower limit of strength, but on the basis of the results available a figure of 4–4½ tons/sq.in. would appear to be reasonable. For the purposes of comparison it is of interest to note that four specimens similar in detail to that used in series BT, and which were tested at Illinois University[3] gave very similar results to those associated with the upper side of the scatter band in series BT. These results are also shown in Fig. 4. However, no details on the standard of welding of these specimens are available.

From the results of the beam tests it appears that transversely welded stiffeners may give a higher fatigue strength than those welded longitudinally, but equally they may give a lower strength. One would suspect that commercial transverse welds, and particularly site welds, would tend to be associated with the lower strength limit, but longitudinal welds are unlikely to show much variation. It therefore seems reasonable to recommend that girders subjected to fatigue loading should have stiffeners welded to the tension flange longitudinally unless very close control of the standard of transverse welding can be maintained.

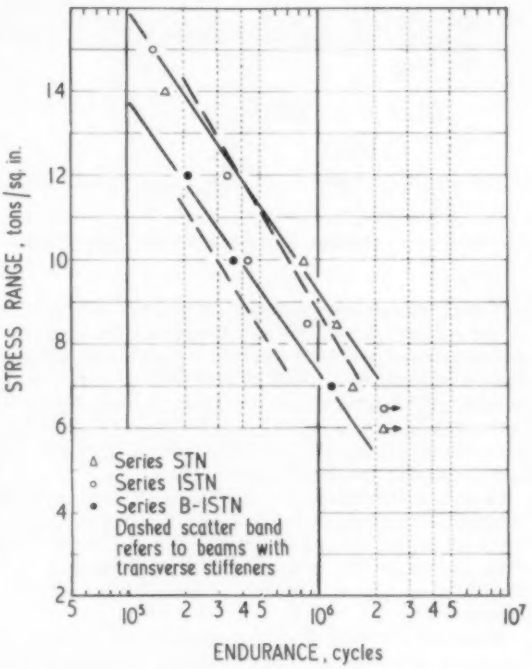
Tests on plate specimens with welded attachments

Transverse gussets (Fig. 2)

The results obtained are given in Table V and are shown in the form of an S/N relationship in Fig. 10.

There was no significant difference in fatigue strength between series 1STN and STN, with gussets welded on one and both sides of the plate respectively, but for both groups there was a considerable amount of scatter. The three specimens fabricated from beam flanges and tested as series B–1STN gave results on the lower side of the scatter band. The scatter band of results obtained in the tests on beams in series BT has also been plotted on Fig. 10, and it will be seen that there is good agreement between the two sets of results.

As stated previously in the discussion of the beam test results, the scatter was almost certainly due to variation in the shape of the weld profile, particularly at the toe of the weld where all failures were initiated. Typical macrosections of the joints are shown in Figs. 11*b* and 11*c*, and it is no doubt significant that the fatigue crack shown in Fig. 11*b* occurred on the side of the joint where the weld made a sharp angle with the plate surface as compared with the other side where the transition point was more concave.

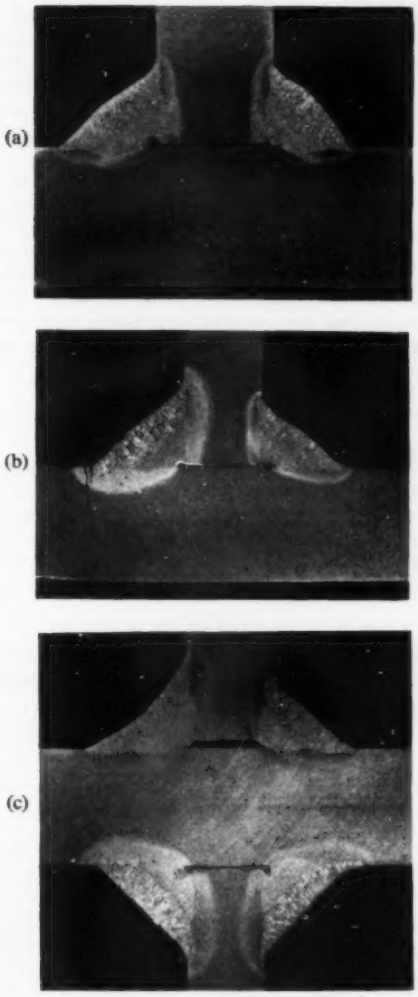


10—Fatigue test results for mild steel plates with welded transverse attachments. Pulsating tension cycle

Table V

Summary of results for Series STN, 1STN and B–1STN
(Plate specimens with welded transverse attachments)

Specimen	*Testing Machine*	*Stress Range tons/sq.in.*	*Cycles to Failure* $\times 10^6$
STN/1	Schenck	0–14	0·166
2	Los	0–10	0·831
3	Los	0–8·5	1·342
4	Schenck	0–7	1·599
5	Los	0–6	2·169 U/B
1STN/1	Schenck	0–15	0·141
2	Schenck	0–12	0·337
3	Schenck	0–10	0·422
4	Los	0–8·5	0·869
5	Los	0–6·5	2·201 U/B
B–1STN/1	Los	0–12	0·209
2	Los	0–10	0·362
3	Los	0–7	1·220



11—Macrosections of typical transverse fillet welded joints: (a) *Beam BT/3;* (b) *specimen 1STN/1;* (c) *specimen STN/4*

Longitudinal gussets (Fig. 3)

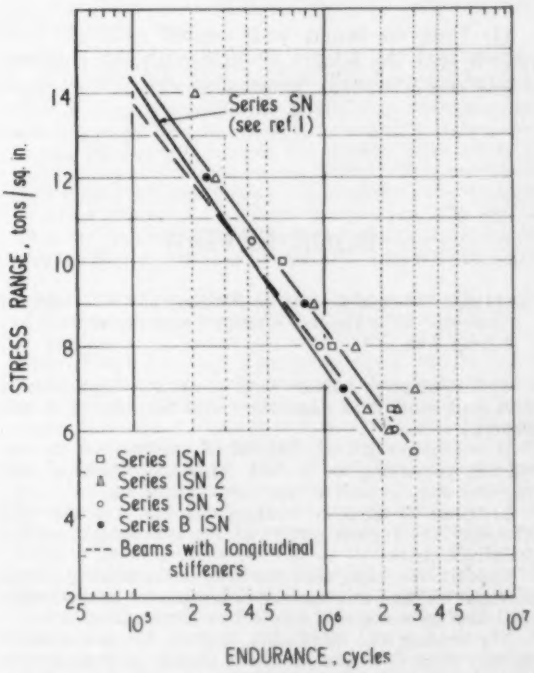
The results obtained are set out in Table VI and are plotted on the S/N diagram in Fig. 12. From this, as in the tests on beams, it is apparent that there was considerably less scatter for specimens with gussets welded longitudinally than for those with gussets welded transversely, and the fatigue strength at 2×10^6 cycles was approx. 6·5 tons/sq.in. This is rather greater than the strength of 5·5 tons/sq.in. recorded previously for series SN, which had gussets welded centrally on both sides of the plate. The difference may have been slightly exaggerated by the use of a different material for the two test series, but it is unlikely that this would account for a difference in strength of about 20%. It therefore seems likely that a slight increase in fatigue strength does result from having gussets welded on one side of a plate instead of on both.

There was a tendency for the specimens in series 1SN 2 to give a slightly higher strength than those in series 1SN 1 and 1SN 3. This was probably due to a small reduction in the stress-concentration factor associated with this particular spacing of gussets, but the increase of strength was hardly significant. The results obtained for series B–1SN, fabricated from beam flanges, were in good agreement with the results for specimens fabricated from rolled plate material.

Table VI

Summary of results for Series 1SN1, 1SN2, 1SN3 and B–1SN
(Plate specimens with welded longitudinal attachments on one side of the plate only)

Specimen	*Testing Machine*	*Stress Range tons/sq.in.*	*Cycles to Failure × 10⁶*
1 SN1/1	Schenck	0–10	0·612
2	Schenck	0–8	1·097
3	Los	0–6·5	2·224
1 SN2/1	Schenck	0–14	0·214
2	Schenck	0–12	0·265
3	Schenck	0–9	0·863
4	Schenck	0–8	1·428
5	Schenck	0–7	2·991
6	Schenck	0–6·5	1·750
7	Schenck	0–6·5	2·387
8	Schenck	0–6·0	2·230
1 SN3/1	Schenck	0–10·5	0·417
2	Schenck	0–8	0·932
3	Schenck	0–6	2·367
4	Schenck	0–5·5	2·955
B–1SN/1	Los	0–12	0·248
2	Los	0–9	0·792
3	Los	0–7	1·248



12—Fatigue test results for mild steel plates with longitudinal attachments. Pulsating tension cycle

Comparison of the results with those obtained for beams with longitudinal stiffeners shows quite good agreement, although the plate specimens were somewhat the better of the two.

Comparison with Other Work

The only work which is directly comparable with that set out in the present report is the programme of tests carried out by Weck[3] on plate specimens with gussets welded both longitudinally and transversely. His results showed that transverse welds were superior to longitudinal welds, having a fatigue strength of 6·5 tons/sq.in. compared with 5·5 tons/sq.in. at 2×10^6 cycles. These results agree well with those obtained in the present work, but the remarks as to the scatter obtained with transverse welds must not be overlooked. An interesting feature of Weck's results was the decrease in fatigue strength obtained for larger endurances, longitudinal welds giving a fatigue strength of 3 tons/sq.in. at 10^7 cycles. The present tests showed no tendency for specimens to 'run out' after 2×10^6 cycles. Hence a decrease in strength for longer life would seem to be a fairly safe expectation.

Conclusions

(1) Tests on beams with welded stiffeners have shown that the fatigue strength with the stiffeners welded longitudinally was approx. 6·0 tons/sq.in. at 2×10^6 cycles. A higher strength can be obtained with transverse welds if welding is good, but variations in weld profile and in particular their susceptibility to undercutting may lead to a serious reduction in strength. The upper and lower limits of the scatter band at 2×10^6 cycles were approx. 7·0 and 4·0 tons/sq.in. respectively.

(2) Tests on plates with welded attachments with similar welding details to those employed in the tests on beams produced results which are directly comparable with the beam test results. It therefore seems reasonable to conclude that any further investigation required on the effect of welding to beam flanges could be carried out on plate specimens with similar welding details, and the results applied to beam flanges, with reasonable confidence.

Acknowledgments

The author wishes gratefully to acknowledge the help and encouragement he has received from Mr. R. P. Newman during the progress of this work. He is also glad to acknowledge the assistance given by his colleagues, particularly Mr. H. J. Tuck who was in charge of the testing.

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2. N. G. KOUBA and J. E. STALLMEYER: Private communication.
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BOOK REVIEW

G. HAIM: "*Manual for Plastic Welding, Vol. III–Polyvinyl Chloride*", 1959, London, Crosby Lockwood & Son Ltd., 324 pp. (50*s*.)

This book gives relevant facts about polyvinyl chloride and deals more than adequately with the welding of this material.

It will be particularly helpful to readers new to the subject, presenting as it does, historical, chemical and physical data, as well as ideas on applications.

Lecturers in technical colleges will find it useful, and Chapter XVIII gives details of the syllabuses used for training courses.

Readers who have had experience in the welding of this material will find this book of much interest, and possibly an added incentive to develop their fabrication work.

The welding and fabrication of p.v.c. has grown enormously since 1947 and the many references given in this book will help readers to follow up specific points which cannot be covered in one publication.

In Chapter I general chemistry and physics is dealt with together with useful tables on the chemical resistance of plasticized and unplasticized polyvinyl chloride. In connection with the former, however, many readers who have had practical experience in this field will be very dubious of using plasticized material at 180°F.

Although this book is mainly devoted to welding, the chapter on manufacture, simply explained, is well worthy of inclusion.

The reader is left in no doubt that hot-gas welding is the most important method of welding polyvinyl chloride and the ingenuity that has gone into the manufacture of the welding torches is emphasized in the chapter devoted to this subject. Chapters IX and X give clear indications of making welds by the hot gas method, emphasizing the right method of deposition.

The applications of polyvinyl chloride in industry are covered thoroughly, and the chapter on suitable workshop equipment will be very useful to newcomers to this field. Applications considered in detail include tank lining with plasticized and unplasticized p.v.c., pipe lines and duct lines, and uses in the building industry; Chapter XVII, with the aid of good photographs and diagrams emphasizes the scope of applications in industry.

The elementary approach to fabrication has not been neglected, and the author has found it possible to include a chapter on the general information on the working and forming of the material, an essential feature for any fabricator before he contemplates starting actual work.

Engineers and pipe fitters, in particular, will find Chapter XIV exceptionally useful; much information on pipe sizes, bursting pressures, tolerances and so on, is given in a convenient tabular form.

In conclusion, this is a book that experienced fabricators, lecturers and students would be well advised to read. The references, sketches, and photographs found throughout the book, together with the six page colour section giving close-up photographs of welds, make it a most valuable contribution to the technology of polyvinyl chloride.

D. W. SHORTEN

DISCUSSION AT THE SYMPOSIUM ON

Fatigue of Welded Structures

A Symposium on the Fatigue of Welded Structures was held at Cambridge University from 29th March to 1st April, 1960, jointly organized by the British Welding Research Association and the Engineering Department of the University.

Eleven papers were presented for discussion; these were published in the March and April 1960 issues of B.W.J.

The discussion on the first seven papers was published in the July and August issues of B.W.J. *Further discussion on the remaining four papers presented in Sessions V and VI now follows.*

Session V

Factors Influencing the Fatigue Behaviour of Welded Aluminium* *By J. E. Tomlinson and J. L. Wood*

The Effect of Mean Stress on the Fatigue Strength of Aluminium Alloy Butt Welded Joints† *By K. W. Gunn and R. McLester*

The first paper was introduced by Mr. Tomlinson and Mr. Wood, and the second by Mr. Gunn.

Mr. Gurney (B.W.R.A.): As the authors have said, little work on different forms of joint in aluminium alloys has been done. It might be of interest at the beginning of this session to outline some results obtained from a current investigation of fillet welded (Mig) joints in NP.5/6. Figure *W* shows three S/N curves for specimens with non-load carrying longitudinal fillets. The condition of the specimens varies between as-welded, annealed and locally pressed, and at 2×10^6 cycles the pulsating tension stress limits are approximately $1\frac{3}{4}$, $2\frac{1}{4}$, and $4\frac{1}{4}$ tons/sq.in. respectively. Comparing this result with Fig. 7 of the paper by Tomlinson and Wood it will be seen that annealing does not show up as favourably as found by the authors; on the other hand local pressing is quite effective and I would suggest the method is to be preferred to spot heating owing to the difficulty of using the latter method on light alloys, due to their low melting point and high thermal conductivity.

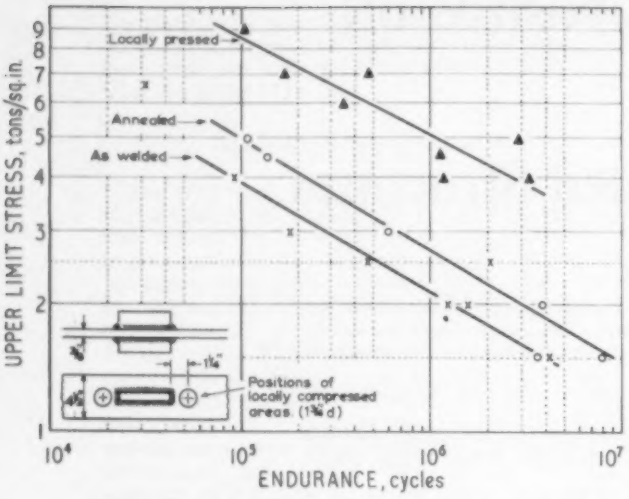
Figure *X* gives results for longitudinal, load carrying fillet welds. Strengths at 2×10^6 cycles are reduced but again local compression is effective. A similar result is obtained under alternating stressing (Fig. Y) and it will be noted that, in line with what has already been reported, the total range of stress is slightly increased with the reduction of mean stress to zero. The pressing operation was carried out with $1\frac{3}{4}$ in. diameter dies under a load of 250,000 lb, or 46 tons/sq.in. on the die area. The residual indentation was 0·010 in. on each surface.

Mr. McLester (Aluminium Laboratories Ltd.): It is preferred that compressive residual stresses are induced in a weld rather than that the residual tension stresses are merely reduced to zero by annealing. This is because the R/M curve for aluminium alloys rises as the tensile mean stress decreases and continues to rise with increasing compressive mean stress.

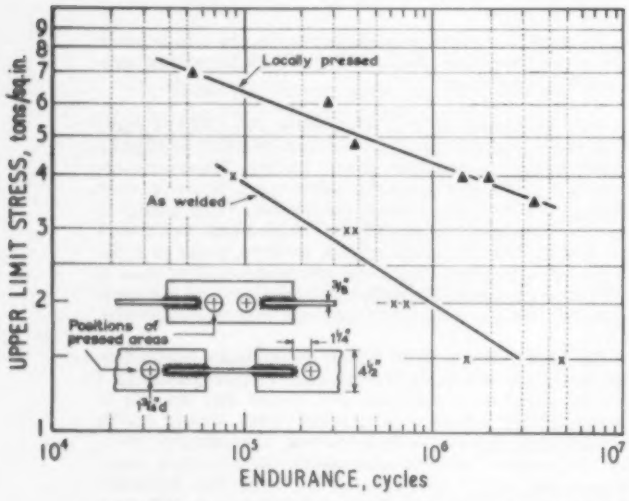
Mr. Tomlinson (British Aluminium Co. Ltd.): I agree that one would not expect annealing to produce as large an effect as local compression or spot heating. There are cases where it might give economic advantages, however, even though the strength rewards are smaller. With regard to spot heating of aluminium alloys, I think a little more work on it should be done because it is, perhaps, easier to apply to actual structures than local compression. The tests in which we used spot heating were exploratory and it is quite possible that the optimum conditions were not employed.

Mr. J. G. Young (B.W.R.A.): The popular conception of the fatigue behaviour of welded Al is expressed in Fig. 4 of the paper by Tomlinson and Wood, but the use of material with a higher 'joint proof stress' should enable higher mean stresses to be employed. The difficulty arises in selecting a weldable aluminium alloy with a proof higher than the 3 alloys tested by Gunn and McLester where the range was limited to 6·4–8·8 tons/sq.in. What are the possibilities? There are the medium strength heat treatable Al–Zn–Mg alloys mentioned in the paper by Tomlinson and Wood, which are probably the most promising and are currently the subject of extensive static strength investigations; there is the heat treatable duralumin type alloy H.15 but here although a high proof may be obtained by post-weld ageing and fatigue strengths are high it is not possible to devise overmatching weld metal which is notch ductile; and, finally, there is the Mg_2Si age-hardening alloy H.30. To get a high 'joint proof stress' in this material, post weld ageing is again required. This ageing has the effect of hardening the H.A.Z. but not the weld metal. The fact that weld metal is not responsive to ageing may not matter in a reinforced butt weld where, as we know, fatigue occurs through the H.A.Z. from the edge of the reinforcement bead. B.W.R.A. have recently completed a fairly extensive investigation into the influence of H.A.Z. properties on the fatigue of reinforced sigma welds

* *Brit. Welding J.*, 1960, vol. 7, p. 250.
† *Ibid.*, p. 201.



W—*Fatigue test results for non-load-carrying fillet welded joints in NP.5/6 (Pulsating tension cycle)*



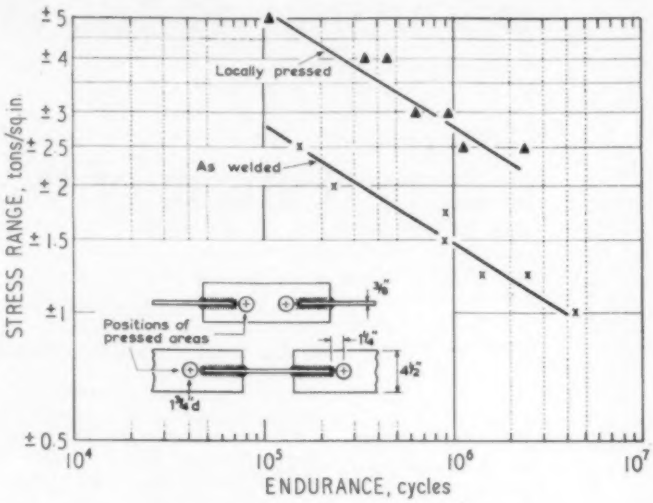
X—*Fatigue test results for 'egg box'-type specimen (Pulsating tension cycle)*

in H.30 alloy, *i.e.*, we modified the properties of the zone through which we knew the fatigue crack would propagate. (*See* Table 1.)

As a measure of the extent to which various treatments modified the H.A.Z. we made hardness surveys and static strength determinations. The width and degree of softening obtained in a normal weld may be illustrated as curve AA′ in Fig. *Z*. By applying a water spray below the plate during welding we were able to modify the hardness as shown by BB′, to give a narrower and harder H.A.Z.

Two original conditions of parent plate – namely fully heat treated and solution treated only were compared, welds being made by the two techniques with and without post weld ageing. Results are summarized in Table 1 which gives static U.T.S. values and fatigue strength values at an endurance of 2×10^6 cycles for the pulsating tension axial stress conditions.

In the as-welded condition it will be noted that, whereas an improvement in static strength of 3 tons/sq.in. occurs



Y—*Fatigue test results for 'egg box'-type specimens (Alternating cycle)*

due to limitation of the H.A.Z., there is no effect on fatigue. This applies both with W and WP plate material.

With post weld ageing, the static strength is further improved, particularly with W plate material, and again this can only be due to an improvement in the H.A.Z., but in this case the fatigue strength is consistently reduced. It has been suggested by Tomlinson (Fig. 2) that the ageing treatment may make the H.A.Z. inherently more notch brittle but it is conceivable also that the metallurgical notch will be more severe due to the inadequate response of weld metal to ageing. Weld metal may thus come back into the picture as a significant factor.

The deleterious effect of post weld ageing is again apparent in some work we are doing on the duralumin (H15WP) type alloys. Some interesting comparisons may be made in Fig. *AA*. In this case argonarc welds were made in both the plain and clad versions of the alloy and again reinforcement has been left intact. These curves are from axial stress, pulsating tension tests, the upper (solid) line is for plain unwelded plate. The short dashes represent the effect of welding which lowers the fatigue strength considerably and this is still lower when post weld ageing is carried out as shown by the long dashed curve. The effect of cladding is interesting. In the unwelded condition clad plate has very much inferior properties in fatigue due to the existence of a weak outer layer in which cracks form relatively quickly and subsequently propagate into the base material. The additional notch caused by welding causes a further but only slight drop in fatigue strength and it is impossible in this case to separate the curves for as-welded and welded and aged specimens.

Whilst Tomlinson and Wood rightly stress the dangers of stress concentration effects and suggest that the most profitable lines of research lie in modifying stress patterns, I think we must still consider reinforcement removal as the most readily applied method of reducing butt weld stress concentrations and then it must be agreed that the weld metal and its extreme edge is still an important field for research activity.

The questions that current planned research are designed to answer are therefore:

(i) To what extent can fatigue behaviour be influenced by the use of overmatched weld metal? The scope here is limited, of course, by the desire to avoid notch brittle weld metal

(ii) Where do fatigue cracks initiate in radiographically

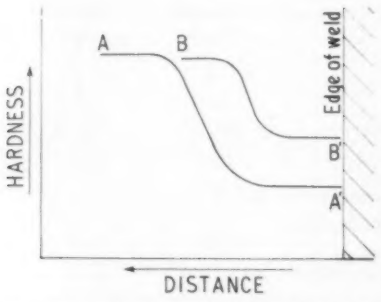
sound dressed welds? Are micro defects of over-riding importance or are constitutional factors involved?

(iii) Can weld metal grain refinement offer any benefit either directly or indirectly by influencing the distribution of defects?

Finally, more work is necessary on initiation in reinforced butt welds. Even though a fatigue crack proceeds through the H.A.Z. its initiation may well be dependent on weld metal factors.

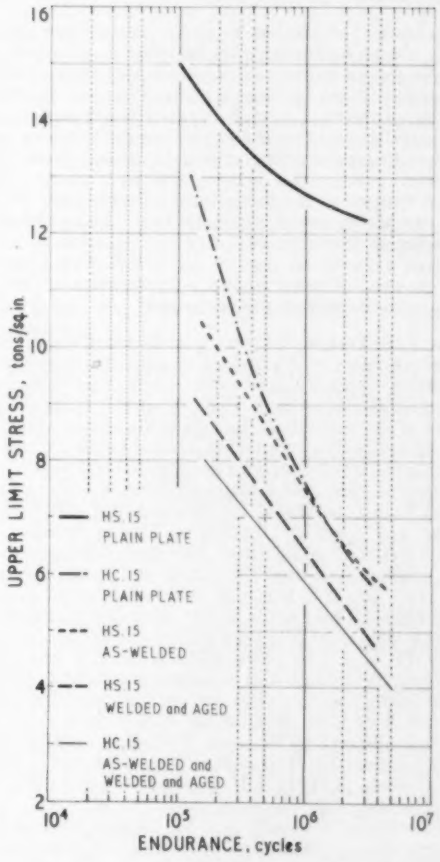
Mr. Tomlinson: Mr. Young has described some extremely interesting work and, at the moment, I would like to comment on one aspect of it only, namely the fact that post weld precipitation treatment of H.30 produces an increase in static strength but no improvement in fatigue properties. We have been determining to what extent the properties of butt welds in this material can be improved by increasing welding speed and current. The B.W.R.A. scheme of a water spray backing is original and imaginative, and may well be capable of practical application. Our approach has been to plot mechanical properties against heat input. An improvement of tensile strength with reduced heat input has been observed, but at the same time the bead profile becomes more convex and one might then expect that fatigue performance would deteriorate because of the increasing stress concentration effect.

I believe Mr. Young said that the weld metal in joints in H.30 did not respond to the post weld precipitation treatment?



Z—Effect of quenching on hardness in H.A.Z.

Mr. Young: It was a 5% silicon material and it responded only very slightly.



AA—Fatigue strength of plain and argonarc welded H.15

Table 1

Static and fatigue strengths of H.30 alloy

H.30 ½ in. plate, 5% Si filler

	Fully heat-treated WP				Solution treated W			
	Water quench		Air cool		Water quench		Air cool	
	As welded	Welded aged	As welded	Welded aged	As welded	Welded aged	As welded	Welded aged
U.T.S., tons/sq.in.	17·0	18·7	13·8	15·8	16·7	19·2	13·6	16·1
Fatigue strength, tons/sq.in., at 2×10^6 cycles	6·0	5·0	6·0	5·0	6·0	5·0	6·0	5·0

Mr. Tomlinson: One feels sure that this is far from being an insoluble difficulty. An addition of 1% magnesium to the filter should ensure adequate response without incurring any penalty in weldability.

Mr. Gunn: I would like to make a contribution in reply to Mr. Young's comments on the effect of ageing in reducing the fatigue properties of fully-heat-treated aluminium alloy welds. If we consider a cross section of the plate at the edge of the weld bead, it is possible that at the surface the proof stress is lower than near the middle before ageing, but after ageing the difference is less marked. The weld with the lower proof stress will be able to withstand higher fatigue stresses at moderate mean stresses than the weld with the higher proof stress because local yielding will occur during the early part of its life. Whether or not this is a true explanation can be confirmed by experimental work to check whether or not the properties of the joints vary across the section as I suggested.

Mr. J. B. Dwight (University of Birmingham): I would like to comment on the degree of emphasis that is placed on different types of research into the fatigue behaviour of welded aluminium alloys. Looking at this from the point of view of the user rather than the research man, two alloys are principally concerned. One is a plate material which, in this country, rejoices under the name of NP.5/6. It is a non-heat-treated alloy and a material which is not unlike steel in that it can be heated for forming and will withstand almost any kind of treatment. Design practice with NP.5/6 has much in common with steel; being essentially a plate material it is used for vessels and ships' superstructures, etc., and it is logical that research work should be concerned with butt welds in this alloy. But the other alloy that is widely used is a very different material, known as HE30 WP. It is a far more subtle alloy; it is heat treated to achieve its strength and is usually produced in the form of extrusions, and one does not use it in anything like the way one uses mild steel. When it is welded one gets a softening adjacent to the weld. It seems to me, therefore, that it is something of a waste of time to be doing research on butt joints in HE30 WP. A butt weld across the whole section is what one tries to avoid in HE.30.

This material is largely used for latticed structures and normally they are fabricated by riveting. On paper one can produce a more economic HE30 WP design by introducing welding, provided the right form of connection is used. As an example, in a statically loaded structure one would connect a truss member to a gusset plate by longitudinal fillets and so restrict the effect of local softening. It is for connections of this kind, therefore, that fatigue data are required.

Finally, I could not resist the thought of using plastics on welded aluminium joints. If epoxy resin coatings give a good result on steel one would imagine the advantage to be gained for aluminium would be greater, for a number of reasons. In the first place it would probably be easier to sell the idea to aluminium users who, after all, already use epoxy resin, instead of welding, for glueing members together. Also I am told that epoxy resin adheres better to aluminium than to steel, so that if exclusion of air from the crack is important, one might again find a better result with aluminium. The modulii of epoxy resin and aluminium are less dissimilar and this could lead to a more effective bridging of any cracks. As Dr Gilde is speaking next perhaps he could tell us just how careful one must be in applying plastic coatings to steel. In making metal-to-metal load carrying joints in aluminium using epoxy resin, it is necessary to carefully degrease the material, and this is done as a normal production technique in aluminium fabrication.

Mr. Tomlinson: I agree with Mr. Dwight's general remarks about the usage of welds in the difficult types of aluminium alloy. There will, of course, be some instances when butt joints will have to be used in heat-treatable materials, for example in the fabrication of long members, although these will represent only a small proportion of the welding done on this class of material.

Mr. McLester: We do, of course, intend to get data for lower strength joints. Our paper presents the first stage of a programme that is concerned with the needs of the designer and it will not be confined to butt welds. It is clearly of interest to us, however, to have recommendations of the kind made by Mr. Dwight so that we can make a suitable choice from the many variants that are possible. With regard to plastic coatings, I would have thought the lower modulus of aluminium something of a disadvantage because of the increased possibility of damage to the coating arising from the greater imposed strain.

Dr. Gilde (Z.I.S.): We have not yet made any experiments on plastic coated aluminium joints, but we have compared the fatigue performance of aluminium beams fabricated by welding, riveting and glueing. The material used was Al/5%Mg (NP.5/6). The form of the beam specimens is shown in Table 2, together with the static strengths and fatigue strengths at 10^6 cycles, stated in terms of alternating bending stress. It will be seen that welding and riveting give the same fatigue result, whereas glueing gives a much improved result. When aluminium structures are to be subjected to dynamic loading it would therefore seem preferable to use glued construction.

Table 2

Details of specimens tested by Dr. Gilde

Type of Construction	*Riveted*	*Welded*	*Glued*
Flange size, mm	50 × 4·5	50 × 5	50 × 3
Web size, mm	100 × 2	100 × 3	100 × 2
Flange angles, mm	25 × 25 × 1·5	—	25 × 25 × 1·5
Section modulus Z, cu.cm	30	30	30
Cross sectional area	9·5	8	8
Deflection under load, mm (1·5 tons on span 80 cm)	2·24	1·85	1·98
Bending fatigue strength at 10^6 cycles (kg/sq.mm)	4·5	5·5	10

Mr. Neumann (Z.I.S.): The two papers are extremely interesting and I would like to add some results from our own work which are complementary. Tests of Al/5%Mg beams (Tig welding) have shown the following results:

Specimen	f_{min}/f_{max}	*Fatigue strength at 10^7 cycles tons/sq.in.*
Beam: web-to-flange joint continuous	−0·7	1·9–2
Beam: web-to-flange joint continuous	+0·2	4·1
Beam: web-to-flange joint intermittent	−0·7	1·2

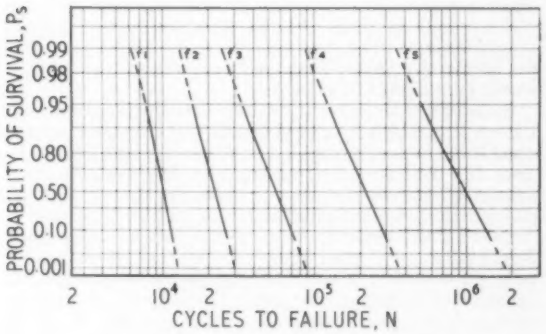
The investigation of welded joints and structural elements in aluminium alloys is being continued and it is planned ultimately to produce a systematization of the results as has been done for steel.

Mr. Tomlinson: These are most interesting results and the agreement with our own simulated tests on monolithic beams with superimposed fillets is impressive. One wonders, however, if agreement is always good provided stress concentration factors and notch sensitivities are high.

Mr. McLester: We have also tested NP.5/6 beam specimens made with continuous web-to-flange welds and the results were about equivalent to those Mr. Tomlinson reports for spot heated beams with a discontinuous weld. In some of the specimens it was necessary to make local repairs by welding and when these occurred anywhere near the maximum stress area they were always the site of crack initiation. No reduction of strength due to the repairs was evident.

Mr. T. Haas (B.W.R.A.): Mr. Gunn has already pointed out that there is an absence of the statistical approach to the presentation of results in this Symposium, but his own approach is open to criticism on account of its arbitrariness.

It should be very simple to adopt a presentation introduced by Weibull, and Freudenthal and Gumbel, which is also widely used by aircraft fatigue workers. This presentation has numerous advantages, and if someone could take the trouble of re-plotting the results presented to this Symposium the picture so obtained would be very revealing, particularly with respect to the points which do not fit the curves.



BB—*Statistical presentation of fatigue results*

The plot (Fig. *BB*) shows P_s, the probability of survival as the ordinate and N, life, as the abscisse, with f=const. stress as a parameter.

$$P_S = 1 - P_F = 1 - \frac{o}{t+1}$$

where P_F = probability of failure
o = order number (or plotting position) with the shortest life being 1, continued in ascending sequence to the longest life up to and including t
t = number of test results

Mr. Gunn: Mr. Haas is right to draw attention to a method of analysis of this kind. I would like to be able to use it but I feel that it is always advisable to obtain approximate S/N curves initially and then undertake a full statistical analysis if it is thought necessary.

When statisticians see fatigue data, they invariably say 'not enough results'—50 results might partially satisfy them and 500 would give them enough to work on. It is therefore going to require a lot of money to obtain detailed information on the spread of fatigue properties of one type of joint, only for someone to say, as does Mr. Dwight, that the wrong kind of joint has been chosen. If money were available and I had the opportunity, I would prefer not to test a large number of butt joints but to test other forms of joints.

Mr. Haas might suggest that our data as it stands should be analysed in the way he has described but one cannot be confident about the shape of the lines in Mr. Haas' diagram. A straight line that adequately represents the results in the middle portion of the diagram can be drawn but can it be assumed that the line is straight at very low probabilities of failure? If, however, anyone thought that they had a better method of interpretation than the one we used, we should be pleased to let them have the results in detail.

Mr. Lewis (W. S. Atkins and Partners): May I ask Dr. Gilde where fatigue failure was initiated in his glued beam specimens?

Dr. Gilde: The failures were located in the aluminium alloy material.

Mr. Newman (B.W.R.A.): My main purpose in making this contribution is to congratulate the authors of this session for what I think are two first class papers.

In regard to Fig. 6 of the paper by Tomlinson and Wood, we have done further work on the question of reinforcement shape since the B.W.R.A. report quoted by these authors was issued, and using the angle α in the same sense as shown in the figure, have tested butt welds in NP.5/6 made by mechanized self-adjusting arc welding, with α varying between 0 and 80°. The results plot very closely to the curve drawn in Fig. 6 if one uses the full range of pulsating tension stress at 2×10^6 cycles and not semi-range as the authors have done. The shape of this curve does, in fact, represent what is commonly observed for the influence of increasing severity of stress concentration. It certainly applies to defects in welds and I would suggest to Mr. Russell that he should not set out to introduce such defects! As part of this more recent work we can give a rather better appearance to the range of strength values quoted by Tomlinson and Wood in Table 6 for NP.5/6 butt welds, made from both sides with the Mig process. The lower limit 0·29 is not particularly good and with controlled welding we are now getting 0·5.

Finally, Mr. Dwight criticized the research end of the business for mixing up butt welds with HE.30, but in the end he did indicate the dilemma that does exist here. If you are concerned with HE.30 and if you are also concerned with fatigue conditions then I do not see how the choice of butt welds can in any sense be regarded as illogical.

Walter Schütz (Laboratorium für Betriebsfestigkeit) wrote: I should like to support Mr. Haas in his proposal to use statistical methods for carrying out fatigue tests and presenting the test data. It is no longer enough to test a few specimens at some stress or other and then draw a line through the resulting points by rule of thumb. Fatigue is a statistical problem and can be solved only by statistical methods, if at all.

Further, I would suggest that more specimens be tested at or near the fatigue limit and fewer at higher stresses, for the following reasons:

(i) If all the stresses of the load spectrum to which a structure is subjected are below the fatigue limit, only the fatigue limit is of interest to the designer.
(ii) If, on the other hand, the stresses of the load spectrum are more or less above the fatigue limit, the only possibility of predicting the resulting finite life of the structure would appear to be programme or spectrum tests as described by Whitman and Alder.*

**Brit. Welding J.*, 1960, vol. 7, p. 272.

With reference to the latter paper, it may be of interest to record that a considerable number of welded or notched specimens of mild steel have been tested to several bridge spectra at the Laboratorium für Betriebsfestigkeit during the last few years. The spectra referred to were recorded from strain gauges fixed to various members of several longspan and shortspan bridges.

Depending on the shape of the load spectrum the gain in permissible stresses compared to the fatigue limit is quite marked, provided a finite, if adequate, life is accepted. Although it has not been verified experimentally, it is possible that welded joints of high tensile steels will behave better under programme loading than under constant amplitude loading, if only because at high mean stress their superior yield strength allows higher maximum working stresses of the load spectrum to be used. In regard to the lowest stresses of significance to fatigue, it has been shown in a number of programme tests, although to aircraft (gust and manoeuvre) spectra, that stresses lower than 50% of the fatigue limit will have an unfavourable effect on the life to failure. These stresses should not therefore be omitted when running programme tests.

Session VI

Future Research – Metallurgical Aspects*
By W. D. Biggs

Future Research – Engineering Aspects†
By E. M. Lewis

(Chairman: Dr. A. A. Wells)

The two papers were presented by the authors.

Mr. E. M. Lewis: I would like to add that whereas in my paper I have named British Railways Research Department as pioneers in the matter of full-size environmental testing, in fact M.E.X.E. are obviously first in the field, as we can see from the paper of Dr. Whitman and Dr. Alder.

In presenting the paper I would like to try and make good what seems to be a deficiency in the Symposium. I am going to describe, with pictures, some service failures. In the proceedings so far we have shown scores of S/N diagrams based on many hundreds of fatigue failures in the laboratory. We have shown many photographs of laboratory failures. Several distinguished practising engineers have indicated that this work is perhaps a little bewildering and presents a gloomy picture to the practising designer. The often quoted 'visitor from outer space' following our discussions might well conclude that the object of the Symposium was to enable research workers to frighten practising designers for the purpose of gaining support for continued laboratory studies of great academic interest but no practical significance. Though we are all here because we know fatigue to be a real live economic engineering problem just as is corrosion, no one has described service failures or shown us photographs of the real *raison d'être* for this gathering. Indeed, no one has admitted to having seen even one service failure! This omission I now propose to make good. (Mr. Lewis then showed photographs of several types of fatigue fracture in crane gantry girders and subsidiary structure.)

Mr. I. M. Mackenzie (Colvilles Ltd.): In his paper Dr. Biggs has discussed metallurgical problems which are I think of academic interest and importance. I am forced to concern myself with some of the more immediate practical problems of producing steels suitable for use at higher stresses, and producing them at an economic price. Now the present position is that high yield steels are available for use where fatigue is considered not to be a problem. We have tried to produce these steels to meet a demand representative of the majority of structural applications. I would like to get confirmation of this point. If I am correct in saying that in most structural applications fatigue is not at present the limiting factor, then we must say that the relatively restricted use of these high strength steels is attributable to economics and fabrication difficulties and not to any shortcomings in their fatigue properties which make designers fear fatigue failure.

We cannot, of course, neglect the interests of those people who are designing structures for fatigue conditions. It is fairly obvious now that none of the present high tensile steels provides the answer. I would like to suggest that this is really not surprising because most of the very numerous ways of increasing the yield strength of steel simultaneously impair its other useful properties, *i.e.*, weldability, notch ductility, general elongation, creep strength, rupture ductility and so on, and a great deal of effort has gone into the quest for steel compositions that will provide high yield with the other desirable properties at an economic price. I personally am gratified to find that the fatigue strength of the high tensile steels is not, in fact, worse than that of mild steel.

But we must try to be constructive and in this connection I think it would be useful if fatigue cracking were looked upon more as a two-stage process than a single stage process, *i.e.*, initiation and propagation. High tensile steels are sometimes claimed to have good fatigue strength on the grounds of their resistance to initiation. If, however, there is a notch present or if a crack is formed, these steels do not behave well at all. It may be that crack propagation, as could be deduced from the work of Frost at N.E.L., is dependent to a great extent on strain hardening. Practically all the high tensile materials, and certainly all those referred to in this Symposium, have a very high ratio of yield-to-tensile strength and this is indicative of a low capacity for strain hardening. I take the somewhat pessimistic view that it may not be possible to combine high yield strength and good notched fatigue properties in the sort of steel which can be produced at a price attractive to structural engineers. In other words there will be very little metallurgical contribution to the problem of structural fatigue. It is therefore pertinent to ask structural engineers if, in fact, they could take advantage of a steel having similar yield strength to that of mild steel but better fatigue properties.

Failing this we should bear in mind the important effect of design and workmanship on the incidence of fatigue failure which I think will result in fatigue failures always being with us. If high strength steels are to be used under fatigue loading conditions care must be taken to see that they are sufficiently weldable and notch ductile to enable any necessary repairs to be made.

No mention has been made in this Symposium of heat-affected zone cracking which is a major consideration in determining a welding procedure for a high yield steel. I would suggest we should avoid any measures to improve fatigue strength of high yield steels which result in an impairment of weldability and notch ductility since I am convinced that, in the end, these properties are going to prove more important.

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* *Brit. Welding J.*, 1960, vol. 7, p.212.
† *Ibid.*, p. 265.

Dr. W. D. Biggs: I think that perhaps there are two ways in which yield stress can be increased without increasing U.T.S. while at the same time retaining a low capacity for work hardening which is essential in the presence of a notch. One is by pre-straining and re-crystallization. I know this is often not possible in practice, but the effect is to produce a very fine sub-structure, *i.e.*, a fine grain size within an already fine grain size. Some research on the fatigue properties of steels with a pronounced substructure would be most informative. The second suggestion, not entirely serious, is that steelmakers should make their steel by depositing weld metal and rolling this out flat, because the only material I know which combines a high yield-to-ultimate ratio with good ductility is mild steel weld metal. Reference to heat-affected zone cracking was deliberately omitted—if H.A.Z. cracking occurred this would override any metallurgical factors which might affect its fatigue characteristics. I would add one further comment, however. In all the discussion of spot-heating and its advantages no one has yet pointed out that the technique is admirable for mild steel where there is no metallurgy to worry about. In the case of high tensile steel I think spot heating might cause some difficulty.

Mr. W. E. Cowley: I agree with Dr. Biggs that there has not been a sufficient amount of work on metallurgical aspects of the strength of welded joints. We have seen that the H.A.Z. is where fatigue cracks usually start. From our experience of materials such as alloy steels and stainless steels it seems possible to obtain a certain amount of control of the structure in the H.A.Z., but this is a subject that is relatively untouched. Moreover, there are design considerations which affect the stress situation in the H.A.Z. The engineering approach has shown that weld profile is important, but should this not be linked both with joint form and the thickness of the parts joined? The idea of achieving control of both stresses and metallurgical structure has not been studied to any great extent, but it is one of some importance to those of us in the chemical and petroleum industries where plant such as high pressure reaction vessels is built with a prospect of securing perhaps 10 years as a maximum life.

Dr. R. Weck: Undoubtedly the H.A.Z. does require a great deal of further study. The idea that it is more notch sensitive must, however, be regarded with some doubt. As shown in Fig. 1 of Mr. Newman's paper, a fatigue crack starts in the H.A.Z. where it intersects the surface, but it propagates in a direction normal to the surface and does not follow the H.A.Z. The difference in principal stress on these two paths must be quite small initially and this suggests that in fact there is little difference, if any, in the notch sensitivity of the materials concerned.

I want now to turn to Mr. Lewis's paper which I found interesting and amusing. On page 268 he makes reference to me and states that I said that early fears in regard to the effect of intense locked-in stresses, which at that time were the subject of great interest, were not justified. I think this is still true today, because the fears that were expressed were concerned with tensile residual stresses introduced by welding upon which tensile stresses due to service loading were superimposed. Mr. Gurney's diagram, Fig. 10, page 168, shows that in the tensile stress region there is very little difference, if any, between specimens tested in the 'as-welded' and in the stress-relieved conditions. So whilst artificially induced compressive stresses have a beneficial influence it does not seem that the locked-in tensile stresses produced by welding have any deleterious effect under tensile loading. This comment is made to dash the hopes of those who might have thought that regardless of any grave mistakes made in design, a structure would be alright under fatigue conditions provided it was stress-relieved. Clearly this is something on which one cannot rely.

Mr. Lewis also refers to scragging and pre-loading of structures and in this context I want to make two points. I understand that in the case of leaf springs, shot peening is only effective if the surface of the spring is not decarburized in heat treatment, otherwise the surface must be ground beforehand if peening is to secure any improvement of fatigue strength. I would say that the same applies also to scragging, indicating that these treatments are effective primarily in the case of high yield strength materials and cannot be expected to be equally effective in the case of mild steel which is a low yield strength material in which the magnitude of the residual stresses produced, particularly by pre-loading and scragging, must be very small. Spot heating and local compression treatments produce compressive residual stresses of yield point magnitude; consequently one gets a considerable effect upon fatigue strength. But I do not think that pre-loading can be relied upon to induce residual stress of yield point magnitude in the right places. In all earnestness, however, Mr. Lewis refers to pre-loading the crane gantry by running the the crane backwards and forwards under an overload, the intention obviously being to induce residual compressive stresses in the bottom flange. He points out later that most of the service troubles occur in the top flange, which has been neglected by research workers. By running the crane up and down you will obviously induce residual compressive stresses in the bottom flange and tensile residual stresses in the top flange, so I really do not see the point he is trying to make.

Dr. W. D. Biggs: I would like to assure Mr. Cowley that there is a great deal of work on the H.A.Z. being carried out at B.W.R.A.; I hope we might hear something about this today. With regard to the propagation of fatigue cracks, it is my observation that sometimes they do follow the H.A.Z., perhaps as often as not.

Mr. E. M. Lewis: In reply to Dr. Weck, first let me make it quite clear that I regard the locked-in stress pattern improvement, by scragging, as an inferior technique to the deliberate introduction of stresses by spot-heating or local compression; the effect is not so profound and I thought I had made that clear. But with spot-heating you have to know what you are doing. On the other hand, provided there is a dominant pattern of service loading as there is with heavy crane operation, scragging by means of a crane overload automatically sorts out critical points both of stress concentration and of high locked-in tensile stress. The effect is entirely local and does not involve, as Dr. Weck suggested, a general yielding of the whole girder section.

To enlarge upon this, accidental notches, such as those due to arc strike, or unavoidable notches that occur during fabrication, such as welding undercut, are most likely to produce fatigue cracks when they lie in a residual tensile stress field of approximately yield point magnitude, so that at each loading cycle the stress range takes the material at the notch right up to yield. If an overloaded crane is run along a virgin welded gantry, local yielding will take place at such notches so that, during subsequent service when the crane runs much more lightly loaded, the peak tensile stress will fall considerably short of yield magnitude, because of the mechanical stress relief which has taken place during scragging.

Dr. W. Gilde: I agree with Dr. Biggs that fatigue investigations should be placed on a more scientific basis. Mr. Neumann has told us of his theory, but this, of course, relates to design; it does not tell us what happens during the production of a fatigue crack. Personally I do not believe that metallurgical studies will offer the best solution; we have heard that there is little difference between steels when they are tested in notched bar form. In my

opinion it would be informative to study the relationship between the fatigue strength of metals and their surface tension in different fluids. Surface tension between a fluid and metal can be measured, by the capillary tube or the drop methods. The fatigue tests should be done in various fluids. In this way a relationship could be established which could lead to the development of a more general theory. For example, Dr. Weck has shown the fatigue crack initiating in the heat-affected zone. It might be possible to discuss this in terms of the relationship between the surface tension of air and metal zones of different hardness.

Dr. W. D. Biggs: Dr. Gilde's ideas are, as always, interesting and I shall look forward to hearing about his further investigation in due course. The surface tension (or surface energy) may well be extremely important—the metal on the surface of a slipped step is highly reactive at the moment of its formation and gas adsorption at this surface when freshly exposed to the atmosphere, may have an important influence on the fatigue life.

Dr. R. G. Baker: In presenting this paper Dr. Biggs referred to the need for more research to be done on the metallography of the H.A.Z. At B.W.R.A. we are carrying out a programme of research into the metallographic structure of the H.A.Z., using a technique developed by Dr. Calvo.* In this method a disc-shaped specimen is polished and etched on one side and a thermocouple of small thermal capacity is flash welded to the centre. The specimen is then placed in a special cell and argon is continually flushed over the prepared surface. A molten pool is formed on the reverse side with an argon-tungsten arc spot welding torch. When the thermocouple reaches a preset temperature the torch is automatically cut off and the specimen rapidly cools. The thermocouple accurately measures the thermal cycle of the metal adjacent to it; the readings being recorded on a chart. The microstructure can thus be correlated directly with the thermal history. By altering the thickness of the specimen, pre-set temperature, heat input, etc., many different thermal cycles can be obtained.

The results we have obtained show one general feature very clearly. The H.A.Z., where the fatigue crack initiates, almost invariably has a metallographic structure which is particularly notch sensitive. In mild steel one has large prior austenite grains in which there may be Widmanstätten precipitation of ferrite. In high tensile steels the position is even worse. In addition to a very large prior austenite grain size the interior of the grains will probably consist of martensite. In aluminium alloys one tends to produce a large grain size and, if the specimen is re-heated, the grains subsequently become stiffened due to the precipitation which occurs within them. All these systems have certain general features in common:

(*a*) A large grain size
(*b*) A stiffened and/or embrittled grain interior.

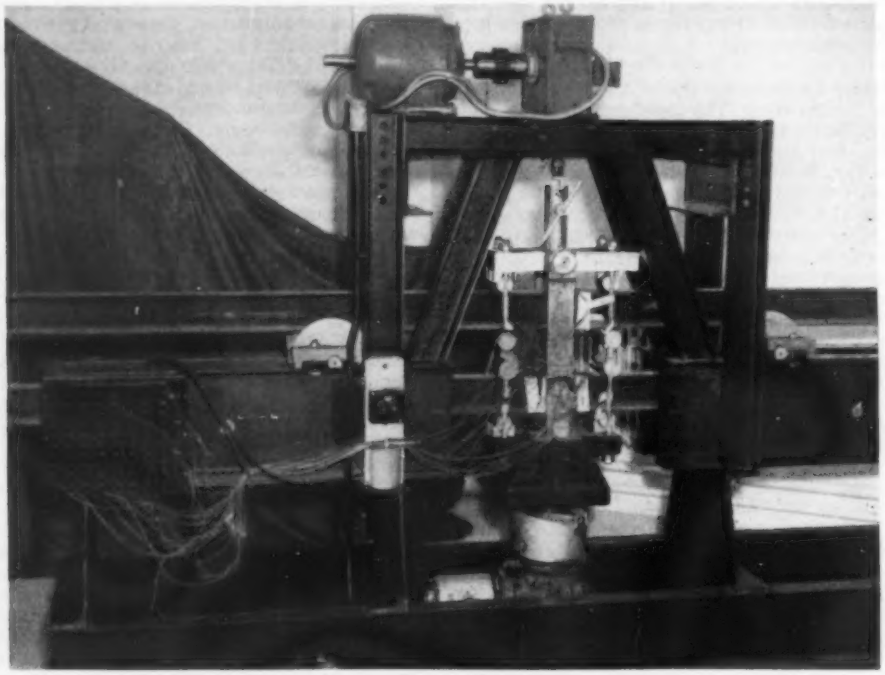
Thus they would all be expected to be especially sensitive to the presence of notches. In order to remedy the situation I would suggest two possible lines of approach:

(i) The possible use of inoculants or other means to make the grain structure as resistant as possible to coarsening
(ii) In the case of steels, refinement of the prior austenite grain interior. This might be done following Dr. Biggs' earlier suggestion by alloying so that fine grained bainite instead of martensite is produced.

Dr. Alder: It will be of interest to Mr. Lewis to know that the panel fatigue machine does not work in the clean conditions of a laboratory but out of doors. The last test reported was in progress for about three months so that some effect from corrosion cannot be discounted.

We feel that mention might be made at this Symposium of other work we are about to undertake with beam testing

* F. A. C. Calvo: British Welding Research Association, 1959. To be published. (See also p. 557, this issue.)



CC—General view of beam fatigue testing machine

machines which is intermediate between the full-scale panel investigation and the study of small specimens at Nottingham University. The beam specimens consist of 12 ft lengths of 4 in. × 3 in. R.S.J. and contain a single type of weld detail, namely 8 in. × 3 in. × ¼ in. cover plates fillet welded to each flange at mid-span. Loading is applied at two points 12 in. apart at the centre of a span of 4 ft. The machines are designed to test two beams, in resonance, together (Fig. *CC* shows the general arrangement) so that variable mean loads can be applied. The frequency is approximately 3000 c/min and a maximum amplitude of ±¼ in. is possible, giving a maximum stress range of ±30 tons/sq.in. on the 4 in. × 3 in. joists; the mean load stress can be varied up to a maximum of 20 tons/sq.in. Six of these machines have been installed.

The programme we have in mind can be set out under several headings:

(i) The influence of initial high loads
(ii) The influence of periodic high loads
(iii) Determination of the lowest damaging load
(iv) The influence of rest periods
(v) Cumulative damage under two-level loading
(vi) Effect of mean stress.

To begin with, this programme will be carried out on steel to BS.968 and at a later stage a material of 40 tons/sq.in., minimum tensile strength will be investigated.

Mr. Lewis: The tests reported by Dr. Whitman and Dr. Alder show that pre-loading or 'scragging' can have a significant effect on fatigue endurance. I would like to ask the authors if they have any further results on the effect of pre-loads of higher magnitude than the rather modest ones referred to in the paper.

Dr. Alder: No further tests on the effect of initial loads have been done as the machine has been occupied with the programme tests.

Mr. T. Baldwin (British Railways Research Dept.): Mr. Lewis mentioned the fatigue testing plant that was under consideration by British Railways Research Department at Derby and it might be of interest if I said something of the kind of work we envisage.

We are already making stress measurements on iron and steel bridges to establish some statistical knowledge of the stresses involved in relation to the traffic.

This information will be supplemented by fatigue tests on members taken from old bridges, so that assessments of useful remaining life can perhaps be made with rather greater accuracy.

Another problem is to establish the fatigue strength of large welded girders where the undetected growth of a crack might have disastrous results. It is possible that a scale effect might have to be taken into account, but this can only be determined by testing and it is proposed, therefore, that fatigue tests of such large specimens should be undertaken. Also, the fatigue behaviour of cross girder connections will be studied, particularly since there may be some standardization of the design of these connections. In other directions, we shall be interested in the end loading of vehicles and the plant may possibly be adapted for measuring the lateral resonance of vehicles. Jack loads of up to 200 tons, with 3 in. stroke at 80 c/min will be available, together with a range of pulsators giving up to 150 tons at 0·3 in. stroke. Slow cycling will also be possible.

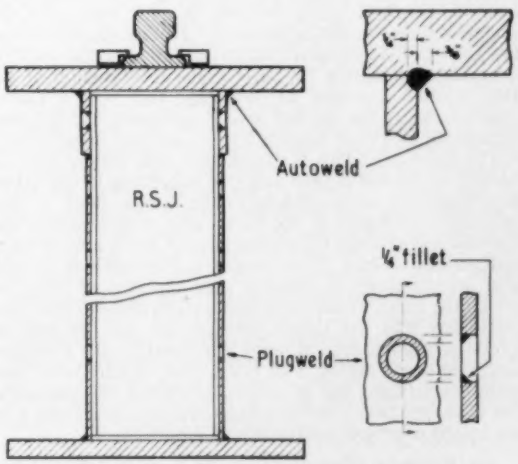
Mr. Charles S. Gray (B.C.S.A.): I would like to make a plea to research workers to help the engineer a little more than they do at the moment. When I consider research work I am tempted to think of two books; one is that piece of classical English humour "*1066 and All That*". The author spent a long time trying to find one memorable date. Now, one or two memorable things have come out of this gathering, one of which is, I think, that welded plate girders fail at 5 tons/sq.in. Bad news travels fast, and this is what is going to be reported from this conference if we are not careful. It simply is not true. Would you be good enough to make clear in your presentation what variables you have considered, but more important still, those you have not considered, because this simple assessment of the plate girder problem only applies to a very limited degree. 'Fatigue' is an easy word to play with, but in 99% of steel structures it does not occur. As a result of an important conference like this, the danger is that some people may apply fatigue considerations in conditions where they are not relevant.

Such a development has already been seen. Some people have designed complete bridges for 2×10^6 cycles of loading apparently for no other reason than that BS.153 gives a fatigue factor for 2×10^6 cycles and it has obviously been thought that this factor should apply to the whole structure rather than to the critical elements for which it was intended. This, I suggest, is largely the fault of the research worker, who has not made perfectly clear the limits within which fatigue factors should operate.

The other book I had in mind I would commend to you as a model of research—applied research; this is "*The Specialist*". Mr. Lemuel Putt was a research worker, a specialist, who sought security and fitness for purpose in his structures and moreover made it quite clear what he was doing. Would the research workers here please do the same!

Mr. Lewis: Mr. Baldwin is in a privileged position and I would make the plea on behalf of us all that when he has the results of his bridge test these should be widely published.

Mr. Braithwaite: Mr. Lewis's suggestion in respect of the web-to-flange joint in plate girders, made at the end of his paper, reminded me of the earlier work done in Germany, in which special flange profiles were produced in order to get away from the simple fillet type of connection. As I remember it this kind of development was by no means free from trouble, and I think Mr. Lewis's idea of splitting a rolled section to make the joint in the web would bring with it certain fabrication problems. If, however, we are to think again about the design of plate girders we should first examine the principles involved and consider whether the H-section is, after all, the best.



DD—Box-section crane girder with plug welded stiffeners

Crane girders are subjected to a considerable amount of lateral loading. Similarly the cross girder in a railway bridge must develop some horizontal force, to be reacted by the main member. The web-to-flange welds are obviously affected by these loads which may be responsible for some of the troubles which have been reported. It seems to me, therefore, that a box-section would be more appropriate; it may not be so economic, but I am thinking particularly of applications where fatigue is important. Fig. *DD* shows a possible design. It has a double web with internal stiffening in the form of a channel or joist section, to which the webs are attached by the proper form of plug weld; that is, a circular fillet weld deposited around the edge of a hole in the plate, not a hole completely filled with weld metal. The stiffeners are not attached to either of the flanges of the box-section, and the web-to-flange joints would be made by continuous, automatic welding.

Such a design might lead to an increase of weight of the order of 5%, but I think it would be substantially more fatigue resistant.

Mr. Lewis: I always listen to Mr. Braithwaite with very great respect and it is with some hesitancy that I suggest the cost per fabricated ton for his design would be significantly higher than for the split beam kind of construction. Moreover, I think we should keep in mind that even a good, automatic weld is vulnerable to transverse bending of the top flange.

Mr. K. W. O. Fenton (English Electric Co. Ltd.): The need for more time and more money has been mentioned by a number of speakers. However, many of us are not interested in the S/N curve but only in the fatigue limit. This applies, for example, in the case of electrical plant. I would appeal, therefore, for an accelerated method of fatigue testing which would enable us to get through the work a lot more quickly than we are able to do at the moment. About 12 years ago Marcel Prot described a method whereby the loading is continuously increased during cycling until failure occurs. If a plot of fracture stress is made against the square root of the rate of increase of load a straight line through the points can be drawn and the intercept on the fracture stress ordinate at zero rate of increase gives the fatigue limit. Is this method generally applicable or must the loading condition in some way take account of the type of service loading as in programme testing?

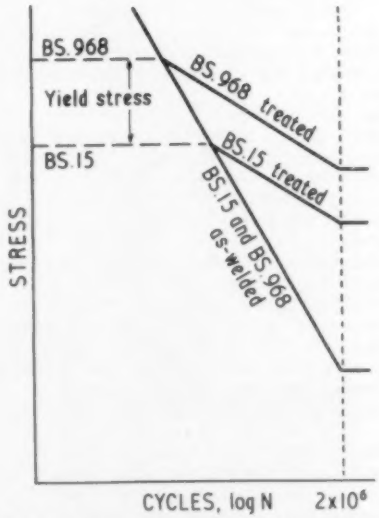
Mr. Newman: Mr. Fenton might be interested to know that some work on the Prot method, as applied to welded joints, has been carried out at Lehigh University. The method appeared to be feasible, but for mild steel the saving in time was not, apparently, very significant because low rates of load increase had to be used. Another method is under examination by the Fatigue Commission of the International Institute of Welding; this is the Locati method. Again the applied load is increased, but stepwise with given blocks of loading cycles, and not linearly as in Prot's technique. This is maintained until failure and the history of the test is then analysed according to the Miner hypothesis for an estimation of the fatigue limit. It thus requires knowledge of the S/N curve, and I believe the method was evolved for the purpose of being able to carry out periodic checks of the fatigue performance of articles that are produced in quantity over a period of time, for which the curve would have been established initially. The possibility that the Locati method can also be used to produce original data is being examined by the Commission and some testing is in hand. First results have been quite encouraging but, as one would expect, this particular use of the method is being studied with care and there is by no means complete confidence at this stage.

Mr. Kerensky (Freeman Fox and Partners): May I first make some comments in reply to Mr. Mackenzie. He referred to the industrial demand for high tensile steel. Perhaps this demand does not at the moment apply to the whole of the structural industry, but I believe that it should. For every mild steel rolled beam there is a high tensile steel counterpart which is lighter and cheaper. If it is not used, then to a large extent this is because of uncertainty in supply. This creates a vicious circle. The steelmakers say there is no demand, so that stocks are not kept, and this in turn leads the fabricator to fear that high tensile steel cannot be readily obtained. Then Mr. Mackenzie asked whether a mild steel with high fatigue properties would be useful. I think it would be of considerable use, particularly in railway bridge and crane gantry applications, provided the steel also had good notch ductility.

Coming to Mr. Lewis's paper, he gives some figures showing the true cost of putting some additional expense into the original structure in order to prolong its life. According to my calculation if one spends 1% more on the original structure, the true cost at the end of 100 years is three times the original cost. Thus it would be just as cheap to replace the structure three times in 100 years as to put 1% extra cost into the structure at the beginning. I think this is an answer to Mr. Braithwaite's suggestion of a double-web girder. In a well designed plate girder the web should weigh a little less than the flanges. If you have a double-web girder I doubt if this could be made without an increase of weight of the order of 20%. Such a girder would thus be ruled out on price.

Mr. Lewis: The figures quoted in the paper were idealized and were intended to do no more than show how the true cost of extra capital expense during construction rises very sharply when the amortization time extends over the comparatively long periods which pertain to building structures, *e.g.*, 25 to 50 years, as compared with the relatively short periods for mechanical plant, etc. There is also another factor, namely that taxation allowances are fixed according to an average estimate of the performance of a structure and it follows that the owner might lose some advantage here by having a structure that is going to give a better than average result.

Mr. Gurney: Dr. Biggs was rather unhappy with the idea of using spot heating on high tensile steels. In so far as



EE—S/N curves of as-welded and spot-heated high-tensile steel specimens

BS.968 is concerned there is every reason to believe that one will, in fact, get a better result from spot heating than has been obtained with mild steel. Tests of fillet welded BS.968 and BS.15 specimens have indicated that there is a similar slope to the S/N curves when these specimens are spot heated. Since both curves pass through the respective yield values on a common as-welded S/N curve (Fig. *EE*) it follows that the increase of strength at 2×10^6 cycles is greater for BS.968, because, of course, the two materials have the same fatigue strength in the 'as-welded' condition.

Dr. Biggs: Provided one is spot heating at temperatures where metallurgical factors do not come into play, one is justified in being optimistic. My point was that if the methods were to produce temperatures in the austenitic region, this could easily give rise to trouble.

And for heat-treatable aluminium alloys I would certainly prefer local compression treatment.

Mr. J. E. Russell (English Steel Corporation): I must support Dr. Biggs on the question of spot heating. This method is used for the straightening of turbine rotors and I recall that in one case, where the rotor was made from a carbon molybdenum steel, star cracks were produced at every point where spot heating had been applied.

Mr. Mackenzie said earlier that one had to ensure a steel was readily weldable. This raises the question of what one means by 'weldable'. We have had experience of welding nickel-chrome bullet-proof plate of about 70–80 tons/sq.in. tensile strength. Pre-heating at 500°C and re-normalizing were necessary and this example is, perhaps, an extreme case. But the point is that if sufficient precautions are taken almost anything can be welded. And if one considers the structural steels of around 35–45 tons/sq.in. then surely it is logical that parallel with the improvements that the steelmaker has achieved there should be improvements in the techniques of welding such steels. For example, the necessary equipment to enable pre-heating to be carried out more easily should be developed.

By the very nature of the welding operation, material in the heat-affected zone, having been heated to temperatures in the austenitic region up to the fusion point, is of a relatively greater hardenability than either the parent metal or the weld (this increase of hardenability being generally greater on low alloy high tensile steels than on plain carbon steels), and this is also just the region in which the cooling rate is most rapid, under conventional welding conditions. These two factors tend to reinforce each other towards producing undesirable martensitic or very low-bainitic structures. It should surely be not impossible to produce devices for directing heat to the 'heat-affected' zone in such a way that the cooling rate there is much slower than the critical. Alternatively, as already suggested by Dr. Baker, the use of inoculants in the steel would at least reduce the local increase of hardenability at this region.

One of the interests of my firm is the welding of very thick sections, for which we feel that the best way of welding high-strength steels will be found in electro-slag welding, as the temperature conditions are inherently more suitable.

Dr. Weck then closed the Symposium and, on behalf of the British Welding Research Association and the Engineering Department, Cambridge University, thanked the authors and participants for their contributions to what had been a most interesting and worth-while occasion.

LETTERS TO THE EDITOR (*Continued from p. 559*)

Hot Cracking in Welds

I am very grateful to Mr. Borland for his constructive comments on my recent Note on Hot Cracking.* As I have already told him personally, had I known that he was about to deal with the subject so thoroughly and effectively I would not have put forward my own Note. As a Note it was written about a year last Christmas and lay fallow in a drawer for almost a year. I was only provoked into publishing it when I saw that papers were beginning to come forward from Russia on the same general lines, and it seemed to me that we in Britain were not taking the subject as seriously as we might do.

I do not wish to deal with Mr. Borland's points in any detail. We agree on almost everything, and I am very happy to know that he has been able to rationalize the subject even further.

I agree with Mr. Borland that I was careless in referring to a wide freezing range as being responsible for cracking. As he reminds us, and as Singer and his collaborators pointed out in the early 1940's, it is the temperature interval between the point at which the alloy first develops some strength and the solidus that really matters. This varies in a broad way with the temperature interval between the solidus and liquidus, but not rigidly. It will be useful to have some such factor as that suggested by Mr. Borland to enable us to say all this neatly and correctly without having to repeat each time a long description of the actual mechanism responsible. Incidentally, Mr. Borland himself falls into the same trap later in his letter!

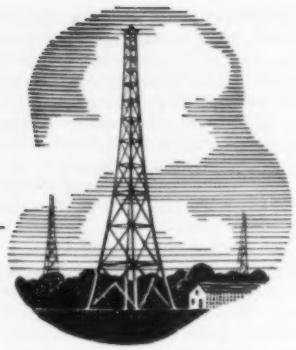
It is true that in extending my ideas to ferritic materials I accepted the empirical formula of Wilkinson and his colleagues which was based on 'mixed' results. I am not so sure however, that Mr. Borland is entirely correct in saying that the mechanisms encouraging liquid to form at grain boundaries in the weld itself and in the zone immediately adjacent to the weld are very different. It is true that they *are* different, but it is my experience with aluminium alloys certainly, that alloys that are susceptible to weld-metal cracking can also crack at the side of the weld if one is sufficiently ingenuous in the steps one takes to avoid weld metal cracking without reducing the solidus temperature. It is true also that Wilkinson *et al* suggested that the beneficial effects of chromium, molybdenum and vanadium were due to their carbide forming tendencies; but in my Note I did not support this. I merely used their results, which appeared to confirm both Mr. Borland's and my own conception of what happens.

W. K. B. MARSHALL

Rockweld Ltd.
Croydon.

* *Brit. Welding J.*, 1960, vol. 7, p. 451.

NEWS
and Announcements



News of the Institute and Branches
B.W.R.A. · Other Societies ·
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INSTITUTE ACTIVITIES

ELECTION OF MEMBERS

The following elections were made at the Council meeting of 9th June, 1960.

Members

E. Ayres (Sheffield); S. Blackburn (Stockport, Ches.); *D. J. W. Boag (Deepcut, Surrey); ‡B. R. Byrne (Guildford, Surrey); J. M. C. Clinch (Pinner, Middlesex); W. E. Cooper (Bourne End, Bucks.); *E. Freeth (Wednesbury); *J. E. Hawksley (Sheffield); F. L. Jackson (Sheffield); ‡W. A. Jenkins (Thurcroft, Nr. Rotherham); A. K. Lilley (Wickersley, Rotherham); *J. R. Merther (West Bromwich); G. H. Smith (Norwich); D. R. Thorneycroft (Edenbridge, Kent)

Associate Members

J. A. Baird (Bexleyheath, Kent); R. G. Baker (Cambridge); A. R. Bingham (Castle Donington, Nr. Derby); D. A. Chowne (Nazeing, Essex); R. J. Cowie (Melton Mowbray, Leics.); †A. H. Cox (Luton); M. S. G. Cullimore (Bristol); I. Davies (Middlesbrough); J. E. Farnaby (Ewell, Surrey); N. S. Farrar (Reigate, Surrey); †R. J. Ibbotson (Banwell, Somerset); D. B. L. John (Llangennech, Carms.); T. E. M. Jones (Redcar, Yorks.); D. Kat (Rotterdam); K. G. Lavender (Welwyn Garden City); W. Law (Dunstable); ‡A. F. Newton (North Romford, Essex); S. K. Upadhyay (Sakchi, Jamshedpur, Bihar, India); J. P. M. Verhaak (Bromborough, Wirral, Ches.); J. Wood (Sheffield)

Companions

R. J. Collins (Bridgwater, Somerset); T. Haynes (South Shields, Co. Durham); D. A. Thirlby (Pollokshields, Glasgow)

Graduates

G. Butcher (Sheffield); G. Greener (Newcastle-upon-Tyne); J. Hackston (Gateshead, Co. Durham); M. P. Huxley (Culcheth, Nr. Warrington); A. J. King (Chalfont St. Peter, Bucks.); A. K. Mukhopadhyay (Garalgacha, W. Bengal, India); S. W. Neville (Saffron Walden, Essex); N. P. Sivadasan (Chittaranjan, W. Bengal, India)

Associates

J. R. Anderson (Bristol); F. Bali (Rotherham); P. B. Bentil (London); L. C. Boyle (Mold, Flintshire); D. G. Campbell (Singapore); F. Carruthers (Bushey, Herts.); T. Clouds (Bilston, Staffs.); H. W. Cowan (Urmston, Nr. Manchester); E. L. Davies (Swansea); J. R. Dransfield (Poulton le Fylde, Lancs.); J. D. Folwell (Northampton); L. Green (Chapel Allerton, Leeds); H. N. Groves (Winole, Nr. St. Helens, Lancs.); W. V. Howe (Ferryhill, Co. Durham); H. O. Jones (Mostyn, Flintshire); T. Jones (Northwich, Ches.); W. P. Kenny (High Wycombe, Bucks.) J. J. Kerr (Hull); W. L. McNabb (Glasgow); S. Moore (Stockport); J. Murphy (Glasgow); A. W. Ope (Lagos, Nigeria); W. J. Pike (Bath); E. W. Ponting (Melksham, Wilts.); G. T. Pye (Leeds); H. L. Roberts (Mazagon, Bombay, India); D. L. Rodbourn (Bristol); G. H. Russell (Pelsall, Nr. Walsall, Staffs.); J. H. Simpson (Nottingham); J. D. R. Smith (Wolverhampton); H. D. Starnes (Southall, Middlesex); H. Timberlake (Luton); C. E. Turner (London); H. O. Vincent (Kingston, Jamaica)

*Transfer from Associate Member
†Transfer from Graduate
‡Transfer from Associate

Two names were omitted from the list published in the June issue of *British Welding Journal*. These are:

J. E. McGarry, Ghana, W. Africa (Companion)
J. D. Galbraith, Warrington (Graduate)

Retiring President's Gift

Before the start of the Council Meeting in July, Mr. E. Seymour-Semper, the retiring President, presented to the Institute a gilt sun-ray electric clock for the Council room. The President, Mr. E. Fuchs, received this with the warm thanks of the Council.

Autumn Meeting, 1960

The Autumn Meeting of the Institute will open with the President's Address *Quality in Welding* which will be presented at the Institute on Tuesday, 1st November, at 6.30 p.m.

On the following day there will be discussion meetings in the morning and afternoon for the presentation of a number of papers on *The Metallurgy of Welding and Brazing*; the 3rd session will be held on the morning of Thursday, 3rd November.

On the evening of 2nd November at 6.30 there will be a Joint Meeting of the Institute and the Institution of

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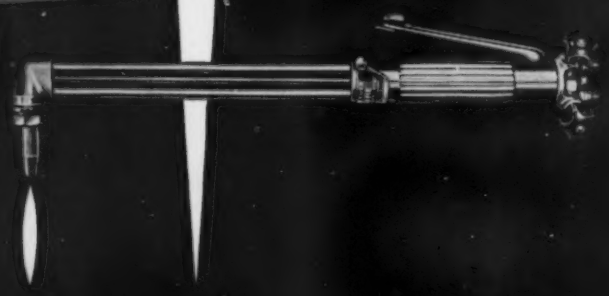


British Oxygen Gases Limited

INDUSTRIAL DIVISION · SPENCER HOUSE · 27 ST. JAMES'S PLACE · LONDON S.W.1

BOC

Metallurgists to discuss the role of metallurgists in fabrication involving welding.

The meeting will close with the Annual Dinner at the Park Lane Hotel on Thursday, 3rd November, at 7.15 for 7.45 p.m.

Notices and reservation forms will be distributed to members in the middle of September. Companies who wish to reserve tables for the dinner are advised to make the earliest possible application because last year all available accommodation was booked some weeks before the dinner.

NEWS OF MEMBERS

Mr. G. Sims-Davies, M.I.Mech.E., has resigned from his position as Technical Sales Manager of British Oxygen Gases Ltd., and has taken up an appointment as General Manager of Hancock & Co. (Engineers) Ltd., of Croydon, Surrey.

Mr. H. W. G. Hignett has been appointed Managing Director of Henry Wiggin and Co. Ltd., as from 1st July, 1960.

Mr. T. H. Kelsey, whose appointment as Assistant General Manager of the Witton Engineering Works of The General Electric Co. Ltd., was announced in October, 1958, has now been appointed Deputy General Manager to Mr. J. J. Gracie, Director of the Company, and General Manager of Witton Engineering Works.

Rear-Admiral W. F. B. Lane, Director of Marine Engineering, Admiralty, and **Mr. H. N. Pemberton,** Chief Engineer Surveyor, Lloyd's Register of Shipping, have been elected Vice-Presidents of the British Internal Combustion Engine Research Association. **Mr. S. J. Wood,** Manager of the Diesel Engine Department of W. H. Allen Sons & Co. Ltd., has been elected a member of the Council of the Association.

Obituary

The Council regrets to record the recent death in Liverpool of **Mr. J. W. Wright**, a Director of Wright (Metal Fabrications) Ltd., Liverpool. Mr. Wright was one of the earliest members of the Institute, having joined in 1923, the year of the Institute's foundation.

Miss Constance Mary Brayden died on 31st July 1960. Many members may remember that Miss Brayden was Librarian of the Institute from 1939 until her retirement in 1957.

BRANCH NEWS

Liverpool — Bridges Old and New

At the Liverpool College of Technology on 9th February last, Mr. J. Kenneth Anderson, M.A., lectured to a large gathering of welders and their colleagues, on the Widnes/Runcorn Bridge Project.

Mr. Anderson described the groundwork of the consultants which led to the acceptance of an arch bridge having a 33 ft. carriageway in three lanes.

Calculations were undertaken on account of the nearby railway bridge and its affect on the aerodynamic forces to cause eddying around the new structure.

There were several objections from interested parties before the design was settled. The Ship Canal Company was worried about the possibilities of creating undue strains on the river wall, and I.C.I. thought the piers in the river would alter its course and the channel near the bank silt up and so stop water intake to their factories. Petitions made to the Parliamentary Committee were rejected.

The foundation contract was then made; this was for a period of 18 months with a £¼ million involved. The next contract, for the steel superstructure, was let to Messrs. Dorman Long. The work included the approach viaducts. A beginning was made in 1958 and it is expected to be completed in December, 1960.

The length of the central span is 1,082 ft. and is the third largest in the world, that at Sydney being 1,650 ft. and at Bayonne 1,652 ft. The side spans are 250 ft. each, and are of the cantilever type; they contribute to the rigidity of the whole and improve the aesthetic appearance of the bridge.

The approach viaducts at Runcorn and Widnes are built of reinforced concconcrete supported on T-shaped piers. These approaches are curved with radii of 1,900 and 750 ft. Reinforced concrete was selected because of the simplicity of the erection, and for economy.

The linking roadwork beyond each side of the bridge includes the new roundabout at Greenway Road in Runcorn and Viaduct Street in Widnes, and this is contracted out to the Lancashire County Council.

150 houses had to be demolished to clear the way for the viaducts, and this small item alone cost around £300,000—about a tenth of the original estimated total cost.

Describing the welding techniques used, Mr. Anderson said that they were at first unhappy about the welding of high tensile steel to BS.548. This is the steel used in the construction of the main arch. The main crossover girders of the bridge deck are entirely welded, the flanges being 2 in. thick. Closely controlled procedures supervised by experienced men finally satisfied them.

The stringers in the deck are made of high tensile steel to BS.968. These involve both shop and site welding; the adoption of welding for this steel was considered a bold step and showed tremendous faith in welding. The steel was preheated to 600°C. to ensure against overstressing when the melt cooled off. There are U frames in the framework of the deck spanning 52 ft., which are prefabricated welded in the shop, but have riveted site connections. The Widnes/Runcorn Bridge is otherwise a riveted structure, although a new bridge designed by the lecturer's firm for the South of England is all-welded.

The keen interest in this lecture was sustained by Mr. Anderson's many points of detail concerning famous bridges around the world, some new, some old. Each was illustrated by a slide. Several well known American bridges were also mentioned and illustrated.

Mr. Anderson showed drawings and photographs of a model of the new Widnes/Runcorn Bridge and pointed out the need to clear the Bridgewater Canal with a span of 130 ft. The old Transporter Bridge would make a notable trinity with the existing railway bridge and the new road bridge, uniquely three bridges side by side, until the Transporter is removed.

Discussing costs, Mr. Anderson had mentioned several items which added disproportionally to them in relation to the extra quantity of steel required to properly embody them. One is the large space which has to be provided for pipes, gas and water and post office cables. Much of these impedimenta was eliminated by the introduction of a tunnel for it underneath the Mersey. A pedestrian footpath, added to the Bridge, is an expensive item in the steelwork costs.

The new Bridge structure will be permitted to weather for nine months and will not be painted during this time. After exhaustive and satisfactory tests, a scheme of painting has been devised. The steelwork will have four coats in the first instance. There is some metal spraying, limited to surfaces abreast the waterlines and under the footpath.

The lecture concluded with a series of coloured slides showing the progress of construction on the new Bridge from its inception up to January, 1960.

The Branch was pleased to have been given the opportunity of witnessing a private view of this important lecture, and the Committee wish to thank Mr. Anderson for his efforts expended on their behalf.

Manchester — Structural Welding

On Wednesday, 2nd March, 1960, a paper entitled *Welding in the Structural Industry* was presented by Mr. A.V. Hooker, A.C.G.I., M.I.C.E., M.I.Struct.E.

The lecture dealt with the influence welding has had on structural design and fabrication, and made reference to

some pitfalls and problems which are not yet fully solved.

The most important effect has been to make practicable the use of fully rigid joints and connections. In this way the portal frame is to some extent replacing the pin-ended lattice structure, and full continuity can be attained in members such as gantry girders or gantry rails. There may be little or no saving in the cost of the steelwork but there is usually a saving in 'dead' space, resulting in reduced capital and maintenance costs for items such as space heating, lighting and painting. Improved appearance is also an important consideration. In short, the material is exploited to greater advantage in a good welded design, and it is true to say that fabrications such as reactor vessels for the nuclear industry could not be made at all but for welding.

Mr. Hooker dealt at some length with plate girder design and fabrication, and included in this the choice of welding process and reduction of residual stresses and distortion. Details of the 110 ft. span Melting Shop girders in the Steel Company of Wales Abbey Works, were given. Other important factors such as fatigue, and brittle fracture were covered in detail.

The lecture was well illustrated with slides and diagrams, and an interesting discussion at 'question time' concluded the evenings proceedings.

A.C.M.

Annual General Meeting

The Branch Annual General Meeting was held on Wednesday, 6th April, 1960. After the formal business proceedings, members and guests enjoyed the showing of the films *Craftsman Welders* and *Welding in the Manufacture of Boilers*.

A.C.M.

BRITISH WELDING RESEARCH ASSOCIATION

Regional Conferences

The Council of the Association is to organize a series of regional conferences during the Autumn and Winter of 1960–61. They will be open only to representatives of Association Members.

This is one step in the Council's plan to improve the communication to members of the results of the Association's researches, and to speed up their application to industrial practice.

A provisional programme has been prepared. Details and tickets of admission can be obtained from the Association at Abington Hall, Cambridge.

Measuring the hydrogen content of steels

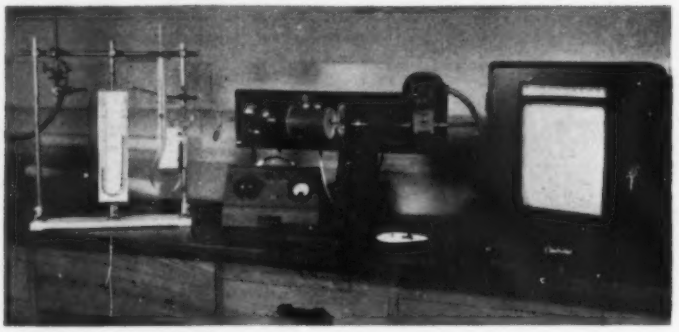
It is generally not appreciated that many quite common gases are soluble in solid metals, even at ordinary room temperature. Such gases, however, can have far-reaching effects on the way in which the metals behave when subjected to forging and welding, and because of the importance of these processes there is a growing interest in possible ways of measuring the amount of gas dissolved.

The B.W.R.A. has recently described a new rapid technique for measuring the quantity of hydrogen dissolved in steels.

Hitherto, the determination of hydrogen in steel has generally been made by heating the sample to about 600°–700°C. under a high vacuum, when the gas is drawn out in much the same way as dehydration of materials can be effected by a combination of heat and vacuum. The vacuum system required for this method, however, is expensive and fragile, and the analysis takes quite a long time.

The new B.W.R.A. technique, which was described at a recent symposium on Determination of Gases in Metals, organized jointly by the Iron and Steel Institute, the Institute of Metals and the Society for Analytical Chemistry, uses a carrier gas principle. In this, argon, an inert gas, is passed over the sample of steel, which is heated in a furnace. The gas evolved is swept along to a hydrogen-sensitive cell from which the result is plotted directly on an electrical graph recorder in the form of a peak. The system is so accurate that as little as 1 p.p.m. of hydrogen can be detected and measured.

The analysis time with this apparatus is 15 min, compared with about 2 hr for the more usual instrument. A patent application has been made.



BWRA apparatus for hydrogen determination

NEWS FROM INDUSTRY

Sprayed metal coatings

The British Iron and Steel Research Association is to undertake an investigation to determine the conditions under which properly chosen and well applied composite protective schemes of sprayed metal coatings and paint can be relied on to protect steel satisfactorily for specified periods.

The work is to be done on a collaborative basis, through the BISRA Corrosion Advice Bureau, with the financial support of all who may be interested in the subject.

Acetylene supply

Hull Steel Radiators Ltd., a newly formed associate of the Swedish company Hjo Mekaniska Verkstad, have recently installed Weldcraft 'Aut-o-Cet' generators to provide a continuous acetylene supply to 20 operating points.

Better design for pressure vessels

Problems concerned with the design of welded pressure vessels have received attention on a continually increasing scale in recent years. However, although considerable data relating both to stresses and to ultimate strength have been built up, variations exist in the way these are applied in national standards. The B.W.R.A., which is currently investigating a number of aspects of pressure vessel design, has therefore suggested that the whole subject should now be discussed in an attempt to rationalize these ideas.

As a result, and in collaboration with B.W.R.A., the Institution of Mechanical Engineers is to organize a Symposium on "*Pressure Vessel Research towards Better Design*" in London on **18th January 1961**.

About twelve papers covering research and design will be discussed during the one-day meeting. The research papers and discussions will take pressure vessel components into account and attention will be directed to problems concerning pressure vessel nozzles. In the design session, papers will include comparisons of continental and British practices and of design codes, and an outline will be given of some of the difficulties associated with the design of pressure vessels for low-temperature operation.

Welding Mission to the U.S.S.R.

In the third week of June a British team of welding experts, led by Mr.

D. J. W. Boag, left for Moscow on a visit arranged by the British Electrical and Allied Manufacturers' Association. While the chief objective was to see the U.S.S.R. Exhibition of Welding in Moscow, the programme also included visits to a number of works manufacturing welding supplies and equipment, and to several institutes and research centres.

The delegation was impressed by the technological work of the research institutes which are fully equipped and staffed by acknowledged experts. These organizations generally make a full investigation of problems submitted by industry, design any necessary equipment and work out optimum techniques, and then apply the chosen solution in the works under production conditions. Not until an adequate solution to a problem has been found is the production work handed over to the industrial concern.

Semi-automatic and fully automatic processes are used to a great extent and, as is well-known, electroslag welding, originally developed at the Paton Institute, has a widespread application. Manual processes were found to be less prominent in the U.S.S.R. and development is considerably behind that in Britain.

A full report on the mission's visit is to be published in due course.

NEW EQUIPMENT AND MATERIALS

Automatic seam welder

For some years the horizontal girth seams of oil storage tanks have been welded on site by means of saddle machines, fitted with submerged-arc welding heads, and straddling the top strake of the tank. This automatic welding method used in the horizontal-vertical position suffers from two serious disadvantages: the large volume of slag needed is difficult to retain in position at the weld; and the arc is not visible to allow centring of the arc.

In a new machine, the 'Circomatic', demonstrated recently at the Liège International Fair, Rockweld Ltd. have overcome these difficulties by incorporating their well-tried 'Comet' CO_2 gas shielded process into the automatic carriage.

Essentially, the construction and operation of the moving carriage are similar to those of the earlier types. Two enclosed platforms straddle the top strake of the tank wall, previously tack-welded in position, and hang from two grooved wheels which are suitable for running on plate edges up to 2 in. thick. Only one wheel is connected to the variable-speed-motor, which provides two ranges of transverse speed, 10–100 in./min or 80–200 in./min. The two wheels can be pivoted to suit varying shell radii. At the lower end of each platform adjustable swivelling guide rollers position the whole carriage against the tank wall. These rollers also act as guides in the vertical direction when the carriage is lifted on and off the tank. Each of the two welding heads is carried on a fabricated arm pivoted to a stout column fitted on each platform. The arm can be automatically raised and lowered through push-button controls. The slag-retaining supports, in the form of articulated copper blocks making a short endless chain, are attached to the welding head arms, and are pressed against the tank wall by spring tensioners.

The welding heads are of the twin motor type as normally used for the Comet process, and are fitted with

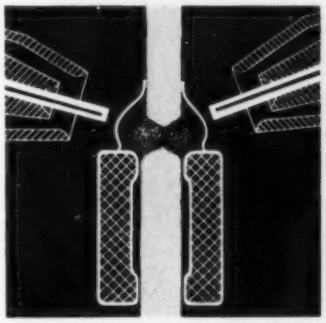


Diagram of Circomatic welded joint

nozzles to suit $\frac{1}{4}$ in. and $\frac{5}{32}$ in. dia. wire. The wires are the standard Comet flux-cored formed steel strip type.

The heads are supported so as to give universal movement for positioning, and a quick-action adjustment allows the positions of the nozzle to be altered during welding. The relative lateral position of the two heads can be set or altered as desired.

The CO_2 shielding gas, supplied from cylinders on each platform, passes through a sheet-metal 'arc box' which is fitted with fine bronze wire brushes around its edges to prevent dispersal of the gas by wind.

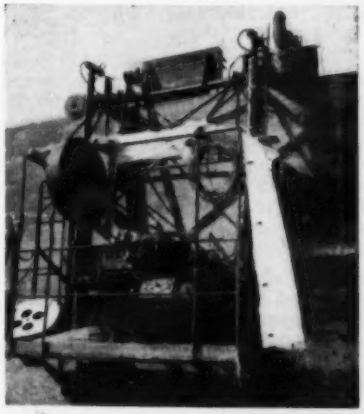
Separate welding generators or rectifiers are provided for each head. These can be two 750 amp continuous duty single-operator machines with an o.c. voltage of 65–85 V, and with a normal drooping characteristic, or four smaller generators in parallel. A 5 kVA three-phase a.c. supply is also needed for the auxiliary equipment.

In operation, after the tank shell plates have been tacked into position and the carriage set on the top edge of the plates, the welding nozzles are set in position with the inside one about 1 ft in advance of the nozzle outside the tank. The slag-supporting shoes are placed against the plate just below the joint.

With the current, voltage, and traverse speed for each arc pre-set to the correct values the leading operator on the inner platform strikes an arc and sets the machine in motion. The second operator, in communication with the first by telephone, can see the back of the first run being deposited, and he starts his arc when about 1 ft. of the other side of the joint has been completed. Subsequent progress is then fully automatic, though each operator can make minor adjustments to his arc during welding. The 'arc boxes' give full visibility to the weld all the time.

The welding is carried out in the 'three-o'clock' position. With plate thicknesses up to $\frac{3}{8}$ in. no edge preparation is necessary. In greater thicknesses a 45° bevel is given to each side of the upper plate, with a root gap of $\frac{5}{16}$–$\frac{1}{16}$ in. according to thickness. For plates up to about $\frac{7}{8}$ in. thick one pass each side is sufficient. Multi-pass welds are easily applied for greater thicknesses.

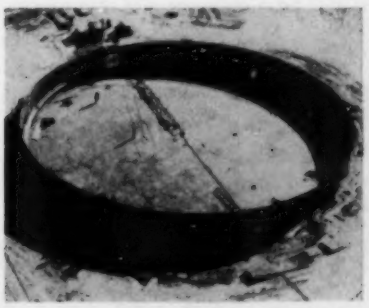
As with the Comet process used in normal conditions, the properties of the weld deposit compare favourably with those of manually deposited welds under



Early design of Circomatic on tank shell

Cover Illustration

Welding head and control panel of Circomatic seam welder



Circomatic unit on site

similar conditions. And the use of CO_2 shielding allows very high currents (and therefore high deposition rates) to be used. In comparison with manual welding this results in remarkable time economies. Thus, a joint between $\frac{7}{8}$ and $\frac{3}{4}$ in. plates in a 140 ft. dia. tank is completed in 30 man hours by the Circomatic process (this includes setting up time) as compared with 300 man hours by a manual technique.

The Circomatic process, designed specifically for storage tank construction, could possibly find application in other fields, where lengths of plate have to be joined (or rolled sections to plate), especially under site conditions. Though the carriage is normally supported oy the plates of a tank shell it could easily be adapted to run on a light gantrn above some other form of construction.

Engine driven generator

A new 'SA 200' mobile welding generator available from Lincoln Electric Co. Ltd., provides 30–275 amp manual welding current, with a 200 amp continuous rating. It is powered by a

Rusten Hornsby two cylinder air-cooled diesel engine developing 21 b.h.p. at 2000 rev./min.

The open-circuit voltage of the generator is adjusted by a shunt-field rheostat, and the welding current is controlled by both series and shunt fields. Polarity of the electrode is quickly changed on the control panel.

The welding unit can be supplied fitted for hand or fast road towing as required.

Manual CO_2 Welding

The Philips manual CO_2 welding equipment, marketed in the U.K. by Research and Control Instruments Ltd., is now in full production after extensive field trials.

The CO_2 welding process has the advantages of high metal deposition rates (12 lb. of metal per hour is claimed for the Philips model) and the ability to weld in all positions without the need to change the welding current and voltage.

The Philips equipment is a three-wheeled unit carrying the wire reel and wire feed mechanism, two gas cylinders with their gas and electrical controls, and the hand welding gun with trigger switch.

The gun with feed cable attached weighs only $3\frac{1}{2}$ lb. and can be used for currents up to 320 amp. The machine head can rotate through 180°, so that with the standard 12 ft. length of feed cable a distance of up to 20 ft. can be welded in one operation.

Three wire sizes, 0·9, 1·2 and 1·6 mm can be used, and the wire feed rate is continuously variable between 6 and 54 ft./min.

STUB ENDS

▶Morrisflex have formed a Wallace Division at their Coventry Factory to produce cut-off machines under licence from Wallace Supplies Manufacturing Co., Chicago, U.S.A.

▶Manchester Oil Refinery group have opened a new Sales Office at Canada House, Chepstow Street, Manchester.

▶On the retirement of Mr. A. E. Ford, O.B.E., F.C.A., Mr. J. F. Perry, A.M.I.E.E., A.M.I.Mech.E., was appointed, from 1st July, 1960, Chairman of Eutectic Welding Alloys Co. Ltd.

▶Murex Welding Processes Ltd., held a special welding exhibition at the Rutherford College of Technology, Newcastle-upon-Tyne 1, from 5th–9th July. The exhibition, one of a series being held in various centres, demonstrated the new Murex automatic welding equipments and the latest Murex hand welding electrodes and equipments.

▶Cook & Nicholson Ltd., of Wear File Works, Sunderland, have been appointed agents for North-East England by Weldcraft Ltd. They will handle sales of gas welding equipment and later electric welding equipment in Northumberland, Durham and the North Riding of Yorkshire.

▶The British Conference on Automation and Computation has arranged to hold in London a Symposium for the discussion of the British papers recently presented at the 1st International Congress on Automatic Control, held in Moscow. The Symposium will be held at the Institution of Mechanical Engineers on 27th and 28th September, 1960.

▶The Factory Equipment Exhibition, organized by the Manchester Chamber of Commerce, *The Financial Times* and *Industrial Equipment News* is to be held at Belle Vue, Manchester, from 21st September to 1st October, 1960.

▶Smiths Industrial Division, with headquarters at Chronos Works, N. Circular Road, London, N.W.2, has been formed to integrate the interests of Smiths Industrial Instruments Ltd., Kelvin and Hughes (Industrial) Ltd., and David Harcourt Ltd. The General Manager of the new Division is Mr. W. M. Cann.

▶The U.K. Instrument Sales, and Instrument Service and Dispatch Departments, as well as the Exports Division, of the Solartron Electronic Group Ltd., have moved to new premises in Cox Lane, Chessington, Surrey (Tel. Lower Hook 2150).

▶K. A. Ballard Ltd. has been formed to act as engineering agents and consultants, particularly in connection with general fabrication for the movement and storage of fluids in the petroleum, petro-chemical, and chemical industries.

▶Dymet Alloys Ltd., an associate company of Rockweld Ltd., and specialists in the production and manipulation of tungsten carbide, have moved from Croydon to new works in Frimley Road, Camberley (Tel. 4433/4).

▶Changes have been made to the names of certain Wiggin Alloys. Incoloy DS is the new name of Nimonic DS; Valray I is the new name for BAC Brightray.

DIARY

9th–10th Sept.—Czechoslovak Scientific Technical Association—Symposium on topical problems of fatigue strength, Prague.

15th Sept.—Liverpool—History of the Manchester Ship Canal with film *Port of Manchester* by E. Greenwood (Byrom St., 7.15 p.m.)

21st Sept. — East Midlands — Works Visit to Stanton Ironworks.

22nd Sept.—Leeds—Ladies Night

22nd–24th Sept.—Conference on the "Theory and practice of ultrasonic inspection" (Queens Hotel, Cheltenham)
Arrangements made jointly by the Institute of Physics' Non-Destructive Testing Group, the Society of Non-Destructive Examination, and the Non-Destructive Testing Society of Great Britain.

24th Sept.—Liverpool—Ladies Day

26th Sept.—Sheffield—Works Visit to Newton Chambers & Co. Ltd., Chapeltown, followed by lecture by W. J. Colton

26th–30th Sept.—School of Welding Technology—Course D1/3 "Welded Pressure Vessels"

28th Sept.—South London (Medway)—*Developments in Automatic Welding* by A. M. Horsfield (Fredrick Braby & Co. Ltd., Thames Road, Crayford)

29th Sept.—East of Scotland—Visit to Henry Balfour & Co. Ltd., Leven, Fife

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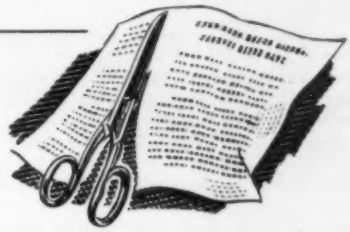

Book Reviews

Additions to the Institute Library

Trade Publications

CONTENTS OF PERIODICALS RECEIVED

This section is intended to give a survey of the current welding literature received by the Institute of Welding Library. The contents lists are not exhaustive; only the main articles in welding journals are listed, and reprints from other journals and short notes are generally excluded. In addition, welding articles from other periodicals are listed. Abstracts of welding literature are given in the Bibliographical Bulletin of Welding and Allied Processes, *published by the International Institute of Welding, and details of this may be obtained from the Secretary of the Institute of Welding.*

Automatic Welding (U.S.S.R., translated by the B.W.R.A.), 1959, October

Submerged arc welding of high-tensile steels with fused fluxes, A. M. Makara, T. M. Slutskaya and N. A. Mosendz

Unfused alloying fluxes for automatic and semi-automatic hardfacing, Yu. A. Yuzvenko

The mechanical properties of welded joints in certain titanium alloys and their corrosion resistance in nitric acid, S. M. Gurevich and L. N. Yagupol'skaya

Programming welding processes, B. E. Paton and Yu. S. Grodetskii

Maximum heating conditions for continuous flashing of compact sections of up to 10,000 mm², S. I. Kuchuk-Yatsenko

Direct acting arc regulators with two-phase motors, E. I. Slepushkin

The present state of welding engineering in Poland and prospects for its development, Yu. Pilyarchik

Weld metal primary crystallization, L. I. Gladshtein

Automatic CO_2 butt welding of thin walled tubes, D. A. Dudko, M. D. Litvinchuk, V. S. Mechev and S. E. Chernovol

Semi-automatic CO_2 butt welding of main pipe lines without permanent backing rings, V. Ya Dubovetskii and V. P. Livinskii

Experience of welding clad steel oil equipment, A. G. Fomin

The half-submerged single side arc welding of 35 mm thick aluminium busbars, D. M. Rabkin and B. A. Steblovskii

Introduction of slag pool using self-fusing fluxes, B. I. Maksimovich

Water vapour as a shielding atmosphere for arc welding, L. S. Sapiro

A new low-alloy steel for high temperature and pressure boiler drums, T. M. Slutskaya

Automatic Welding (U.S.S.R., translated by the B.W.R.A.), 1959, November

Mechanized exposed arc welding with cored electrodes, I. K. Pokhodnya and A. M. Suptel'

Automatic CO_2 welding of 15Kh1M1F steel, B. S. Kasatkin Yu. N. Vakhnin

Impact strengths of welded joints in AMg6 aluminium alloy, A. S. Asnis, D. M. Rabkin and I. M. Savich

Weld metal phase composition when welding AMg6 alloy, V. F. Grabin and D. M. Rabkin

Effects of chemical composition and method of welding on the properties of welded joints in copper, L. E. Fedotov

Effectiveness of weld geometrical dimension control assessed, L. E. Alekin

Research into the strengths of circumferential flash butt welded joints in 325 mm dia. tubing, made with flashing continuous, F. I. Kislyuk and V. S. Lifshits

A high-frequency welding plant constructed as a single machine, K. A. Bykov and L. A. Byalotskii

Experience of the A-550 automatic machine used for electroslag welding with plate electrodes, A. N. Safonnikov

Rods upset using resistance heating, Shop report

Mechanical properties of welded joints in drill pipe after various heat treatments, T. N. Kornev and Z. G. Napetvaridze

A universal twin spot welding machine with current supply from both sides, V. V. Vershinskii, A. V. Meier and V. T. Shapkina

Automatic surfacing of large reduction gear wheel rims with strip electrodes, F. A. Khomus'ko

Welding techniques at the 1959 British Exhibition, Yu. N. Zaitsev

Spectrographic analysis of welds in duralumin type alloys, A. S. Dem'yanchuk and O. P. Ryabushko

The First Baltic Welding Conference, M. S. Zil'ban

The All-Union Conference on Design and Strength of Welded structures

Przeglad Spawalnictwa (Poland), 1960, vol. 12, June

Welding of St52 steel, Z. Szczecinski

Modern steel bridge with orthotropic roadway across Sawa River in Belgrade, J. Sarara

How to qualify welders, Part 1, E. Macalik

Peak temperature determination in welded joint, E. A. Juffy

Schweissen und Schneiden (Germany), 1960, vol. 12, May

Experience with field welded joints in the construction of the Severin Bridge, Cologne, G. Vogel (189–194)

Low railway bridges in welded box section construction, K. Dornen (194–198)

Special design features of the new railway station at Munich with particular reference to welding, E. Hoffmann and A. Coblenz (199–202)

Welding and bonding technique in modern skyscraper construction, O. Jungbluth (203–208)

The application of autogenous pressure welding in the construction of a reinforced concrete bridge, W. Kniewasser (208–209)

The first welded fully hydraulic lock gate, G. Wickert (210–211)

Welding in the construction of cranes and lifting gear, H. Wenzlaff (212–214)

Design of pipeline valves with particular reference to the required welding operations, W. Riebold (214–216)

The application of welding in railway engine construction, G. Piersig (217–219)

Large capacity container vehicle for high pressure gas, W. Wolff and F. Hildebrand (220–221)

Welded spherical containers, H. A. Neumann (221–226)

Autogenous welding in the manufacture of high performance steam boiler plants, W. Muller and W. Blasius (226–229)

Faults during welding repairs and their remedy, K. Weber (229–233)

Hot welding of cast iron with backfire-proof blow-pipes, H. Neumann (233–235)

Application of autogenous flame gouging equipment in the repair of a pipe dryer, A. Buchholz (236–238)

Increased corrosion protection by flame cleaning, H. Ehrenberg (239–241)

Flame hardening of piston ring grooves for marine engines, K. Falkenmayer (241–243)

Rational feed hardening opens new fields for flame hardening, H. W. Gronegress (244–247)

Design for welding using the new IPE rolled sections, A. Reinig (248–251)

Welding and quantity production with particular reference to the manufacture of shell beams for the building industry, K. Huisgen (252–254)

Soudage et Techniques Connexes (France), 1960, vol. 14 March–April

Contribution to the study of the fatigue strength of parts repaired by building-up processes, H. de Leiris and H. Granjon (85–102)

Recommended practice for flash welding, Part 2: Hard carbon steels and alloy steels, IIW Commission III (104–106)

Welding problems in the chemical industry, H. Gerbeaux (107–115)

Recommended practice for the radiographic inspection of circumferential fusion welded butt joints in steel pipes up to 2 inches wall thickness, IIW Commission V (119–124)

Building-up by arc welding in the maintenance of steelworks, S. Gorin (126–131)

Welding and connected techniques in the maintenance department of a large metallurgical factory, L. Bonnier and M. Doncourt (131–140)

Note relative to the conditions of application of the hardness test in view of the determination of the quality of a spot weld on steel, IIW Commission III (147)

The Stabilizer, 1960, vol. 27, Spring

The Llandarcy—Angle Bay crude oil pipeline, W. Hillhouse (7–10)

Automatic horizontal/vertical welding for nuclear power plant construction, J. Danks (11–13)

Tubular fabrication, Part 3, A. Scott (14–16)

Welding Journal (U.S.A.), 1960, vol. 39, May

Welding on high-pressure gas-transmission pipe lines, R. R. Wright and R. S. Ryan (473–477)

Gas metal-arc welding of low-carbon steels, G. Christopher and R. C. Becker (478–487)

Service failures of pipe weldments, H. Thielsch (488–495)

Gas tungsten-arc welding aids construction of manned research vehicle, W. L. Arter (496–497)

The science of arc welding, Part 2, C. E. Jackson (177*s*–190*s*)

Photoelastic-coating technique for determining stress distribution in welded structures, F. Zandman (191*s*–198*s*)

Time-temperature parameters affecting corrosion of 18Cr–8Ni weld metals, T. J. Moore (199*s*–204*s*)

Some observations on the Kinzel and drop-weight tests, S. A. Agnew, M. D. Mittelman and R. D. Stout (205*s*–211*s*)

Welding of galvanized steel-cracking mechanisms and development of solutions, J. F. Rudy (212*s*–218*s*)

Hot-cracking test for CO_2-shielded metal-arc welds, R. W. Ramsey, R. A. Keidel and J. N. Kuhr (219*s*–224*s*)

ADDITIONS TO THE LIBRARY

BOOKS AND PAMPHLETS

ALUMINIUM COMPANY OF CANADA LIMITED. *Aluminium welding course lectures*, prepared for the Aluminium Co. Canada Ltd, by Aluminium Laboratories Ltd., Kingston, Ontario. Montreal, ALCOC Ltd., 1957.

Aluminium welding and allied processes. Section 6: I.M.A. and A.T.A. procedures. Montreal, ALCOC Ltd.

BRITISH STANDARDS INSTITUTION. B.S.1389:1960. *Dimensions of hose connexions for welding and cutting equipment*. London, B.S.I. (Price 4*s*)

Attention is drawn to the desirability of fitting safety devices to hose connexions for protection against the effects of flashback although it is not made a requirement of this standard.

B.S.1542:1960. *Equipment for eye, face and neck protection against radiation arising during welding and similar operations* London, B.S.I. (Price 5*s*)

Specifies requirements for equipment to protect an operator above the shoulders against harmful radiation when engaged in welding, cutting and similar operations. The equipment is designed to give protection against radiation of wavelength greater than 2000 A. London, B.S.I. (Price 5*s*)

B.S.3019:Part 2:1960. *General recommendations for manual inhert-gas tungsten arc welding*. Part 2: *Austenitic stainless and heat-resisting steels*. London, B.S.I. (Price 5*s*)

Gives recommendations on general workmanship, materials and equipment for the manual inert-gas tungsten arc welding of austenitic stainless and heat-resisting steels with 16/20% Cr –7/12% Ni and 20/26% Cr–12/20% Ni. Certain of the recommendations are applicable to the automatic process but are primarily intended for manual welding of plate sheet and strip up to $\frac{3}{4}$ in. thick, bars and forgings.

B.S.3179:Part 1:1959. *Comparison of British and overseas standards for steels*. Part 1: *Chemical composition of wrought carbon steels: British Standard, S.A.E., and DIN*. London, B.S.I. (Price 6*s*)

The steels are arranged in ascending order of the maximum carbon content, bringing similar compositions into close proximity.

B.S.3228:Part 2:1960. *Procedures for obtaining properties of steel at elevated temperatures*. Part 2: *Rupture strength*. London, B.S.I. (Price 3*s*)

BS.219:1959. *Soft solders*. Specifies requirements for non-antimonial and antimonial soft solders for general use and those for use at higher temperatures. London, B.S.I. (Price 4*s*)

IIW DOCUMENTS

Issued for Publication

The following document has been issued by the IIW for publication, and may subsequently be published in the B.W.J. *Single copies of the duplicated text may be obtained immediately for a small charge from the Scientific and Technical Secretariat of the IIW, 32. Bd. de la Chapelle, Paris 18e.*

IIS/IIW-49-60 (Commission IX—"Behaviour of Metals Subjected to Welding"): "**Contribution to the Study of an Acceptance Method of Testing for Weldable Steels C and D using the Vee-Notch Charpy Test, on the Basis of a Conventional Specimen**", H. Herbiet (Belgium) and S. Descovich (Italy).

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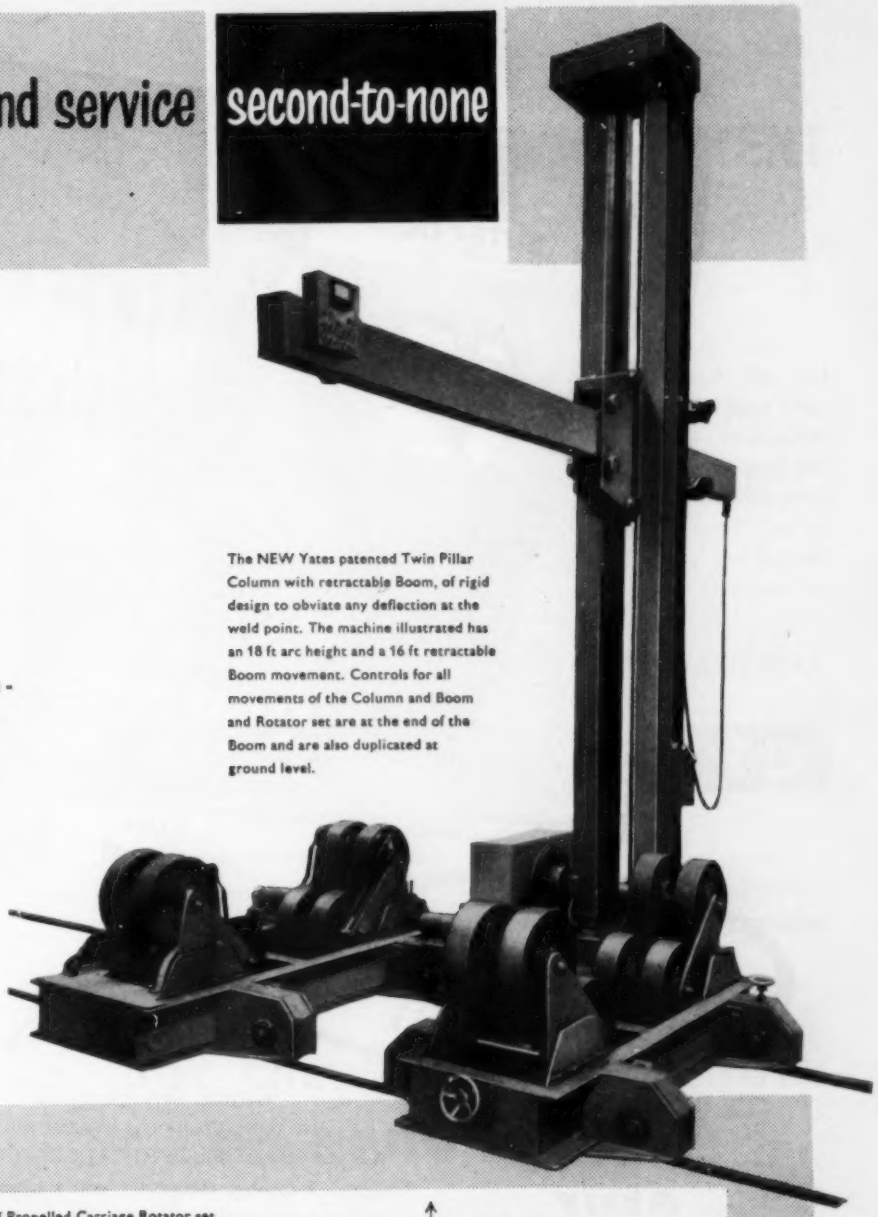

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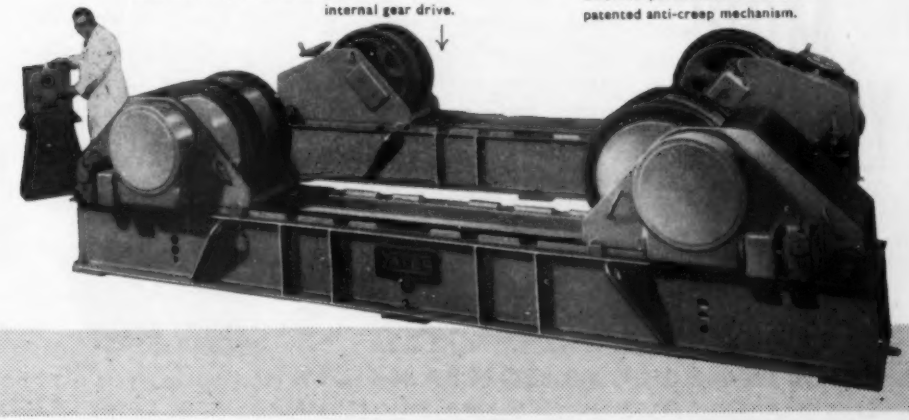

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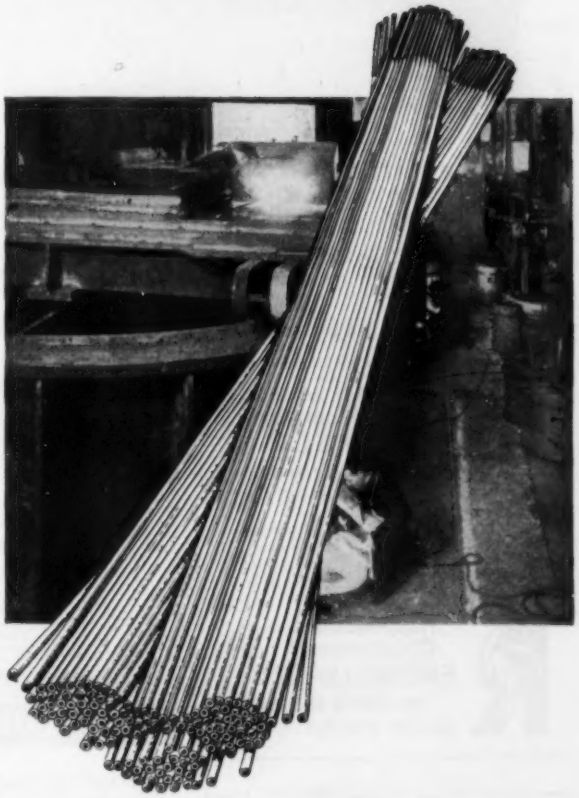

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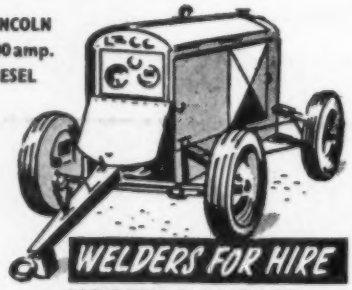

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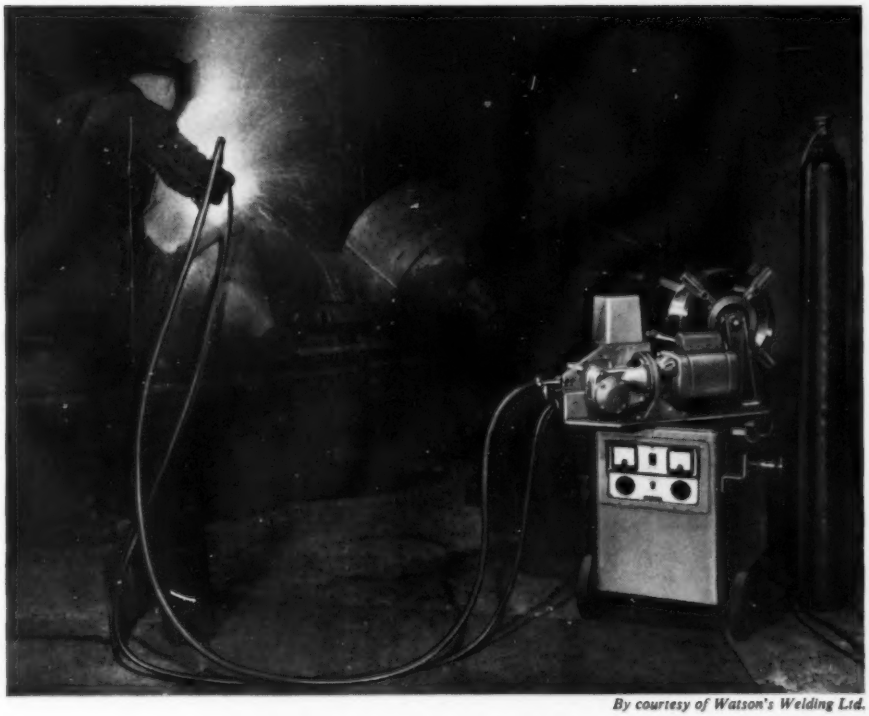

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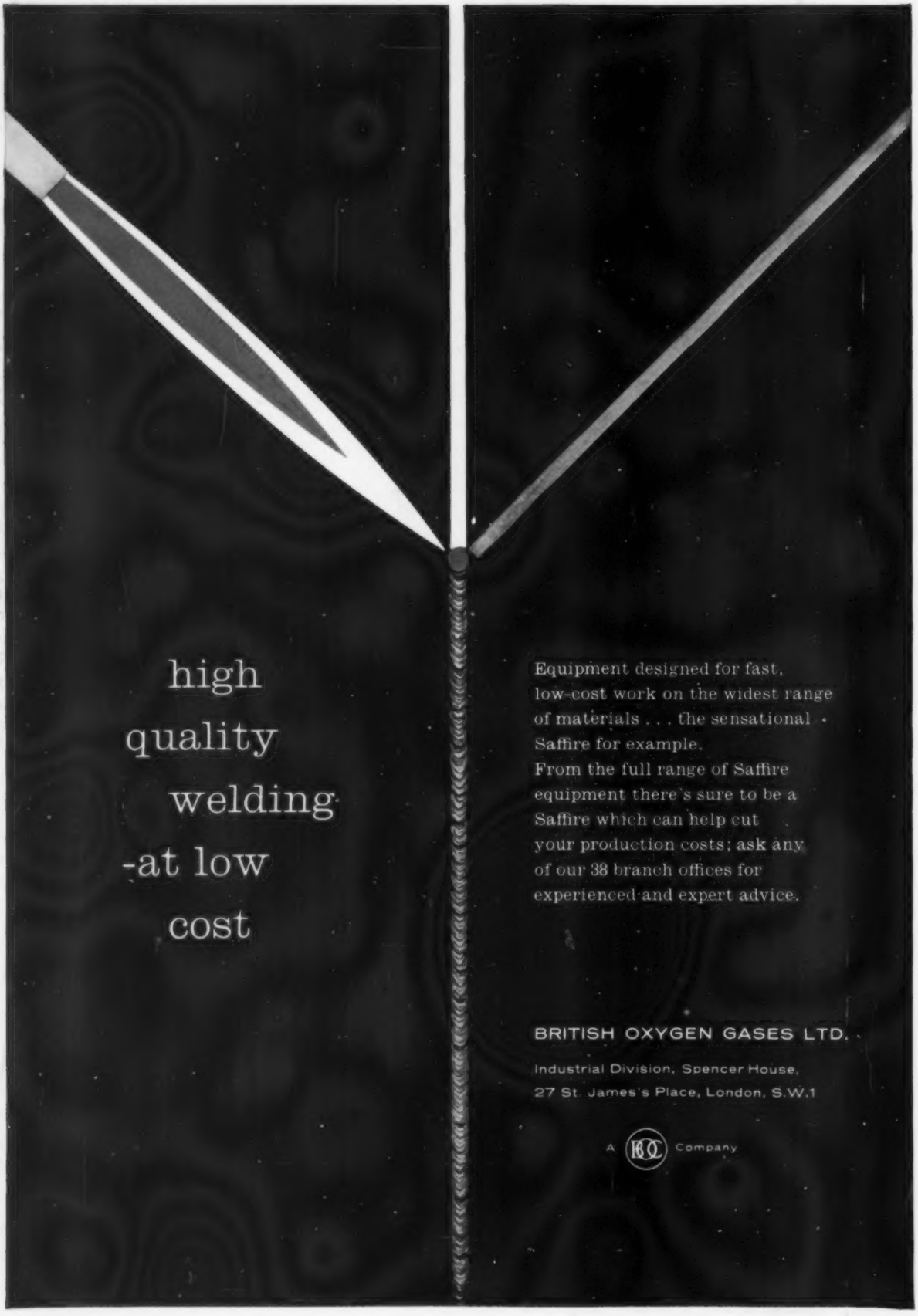
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